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ORIGINAL ARTICLE

Reliability of electromyography during 2000 m rowing ergometry

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Abstract

Purpose This study aimed to investigate the reliability of surface electromyography (EMG) assessed at seven muscles during three repeated 2000 m rowing ergometer sessions.

Methods Twelve male well-trained rowers participated in a repeated measures design, performing three 2000 m rowing ergometer sessions interspersed by 3–7 days (S1, S2, S3). Surface electrodes were attached to the gastrocnemius, biceps femoris, gluteus maximus, erector spinae, vastus medialis, rectus abdominis and latissimus dorsi for EMG analysis.

Results No differences existed between 2000 m sessions for EMG amplitude for any of the seven muscles ($p = 0.146$–0.979). Mean coefficient of variation of EMG for 6 of 7 muscles was 'acceptable' (12.3–18.6%), although classed as 'weak' for gastrocnemius (28.6%). Mean intra-class correlation coefficient values across muscles ranged from 'moderate' to 'very large' (0.31–0.89). Within-session EMG activation rates of vastus medialis were greater during 0–500 m and 1500–2000 m segments, compared with 500–1000 m and 1000–1500 m ($p < 0.05$). Values for biceps femoris and gluteus maximus were significantly higher during 1500–2000 m compared to 500–1000 m and 1000–1500 m ($p < 0.05$). The general pattern was for higher activation rates during 0–500 m and 1500–2000 m compared to 500–1000 m and 1000–1500 m. However, there were no between-sessions differences in EMG for any of the 500 m segments ($p > 0.05$).

Conclusion Reliability of EMG values over repeated 2000 m sessions was generally 'acceptable'. However, EMG was seemingly not sensitive enough to detect potential changes in neural activation between-sessions, with respect to changes in pacing strategy.

Keywords Reliability · EMG · Muscle activation · Rowing · Time trial

Introduction

Surface electromyography (EMG) has frequently been used to identify muscle activity patterns during cyclic locomotive exercise, such as running, cycling, and rowing [1]. Recording EMG during such exercise has many applications; for instance, identifying the magnitude of muscular activation during different intensities of exercise, and effects of equipment modifications on activation patterns [2]. The between-sessions reliability of EMG during athletic locomotive actions, such as endurance cycling and running, has previously been established. Coefficient of variation (CV) values have been reported between 7 and 20% for running and 11 and 35% for cycling across a range of muscles [3–6]. Although 10–20% variation would be considered as high in respect to physical performance tests, the naturally higher variability of EMG has been determined as 'acceptable' over repeated sessions [3–5, 7, 8]. The inherent variability in EMG during locomotive actions has been attributed to factors, such as variations in sensor placement, and measurement normalization including task specificity, as well as intra- and inter-participant specific factors, such as acute fatigue, variations in pacing, motivation and variance in activation rates across the sample [3, 5].

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Assessment of EMG during rowing is considered to be an essential method for analysis of neuromuscular activity within the recruited muscle groups [9]. Information regarding muscular activation during rowing can be utilized within technical modeling to improve performance, reduce the risk of injury and also inform training program design [2, 10]. A number of studies have investigated EMG during rowing. EMG activity across five lower body muscles has been assessed during on-water rowing training, with correlation coefficient values showing moderate to good reproducibility (0.61–0.98), across a variety of exercise intensities as featured within a prescribed single training session [11]. Guével et al. [11] reported that the muscles of the quadriceps (vastus lateralis, vastus medialis, rectus femoris) and hamstrings group (semitendinosus, biceps femoris) were highly activated during the propulsive phases of the rowing stroke. Comparatively, surface EMG values across eight muscles (of both upper and lower limb) have been assessed during on-water and ergometer 1000 m time trials, with higher muscle activation evident during the ergometer session, which corresponded with a faster performance time compared to on-water [12]. Other investigations have reported prominent muscular activation during rowing for muscles of the lower torso (erector spinae, rectus abdominis), upper body muscles involved in pulling motions (latissimus dorsi, biceps brachii) and additional lower body regions, such as the gluteal (gluteus maximus) and lower leg (gastrocnemius medialis, soleus) [13, 14].

Despite the aforementioned investigations which have assessed EMG during rowing, no research, to the authors' knowledge, has assessed surface EMG across a range of muscles during repeated 2000 m rowing ergometry sessions. Therefore, the current study represents a novel area of investigation. Since 2000 m is the standard international racing distance within rowing, assessment of 2000 m rowing ergometer performance is frequently featured within empirical interventions and the assessment and profiling of elite level rowers [15–18]. When assessed as a performance measure the 2000 m rowing ergometer test has shown good reproducibility (CV = ˜2%) [19–21]. Evaluation of the reliability of EMG during 2000 m rowing is essential to determine the appropriateness of EMG as a research tool for such exercise, specifically at this Olympic distance, and particularly where interventions are implemented [2, 22].

The aim of this study was to investigate the reliability of surface EMG assessed at seven muscles during 2000 m rowing ergometry over three separate sessions. It was hypothesized that surface EMG recorded across seven muscles would show 'acceptable' reliability (CV = 10–20%), similar to that reported during endurance running and cycling.

Methods

Participants

Twelve, well-trained, male competitive club rowers volunteered to take part in the study (mean ± standard deviation; age 23.6 ± 5.1 years, stature 1.86 ± 0.05 m, body mass 86.5 ± 8.4 kg, 2000 m rowing ergometer time 6:33 ± 0:09 min:s, and rowing experience of 7.2 ± 5.4 years). The cohorts of participants were featured in a previous study (same data collection occasions) which detailed consistency of pacing of the repeated 2000 m sessions (S1, S2, S3) in relation to power output and metabolic responses [19]. All participants had competed at national level events, such as the 'Head of the River Race', the 'Henley Royal Regatta', the 'National Rowing Championships of Great Britain', or the 'British Universities and Colleges Sports Rowing Championships'. Additionally, participants had extensive prior experience of performing 2000 m rowing ergometer tests prior to their involvement in the study. Participants were informed of the experimental procedures and any potential risks involved and provided written informed consent to participate in the study. The study was approved by the local ethics committee in-line with the Helsinki Declarations for research with human volunteers.

Experimental protocol

The study followed a repeated measures design to determine the reliability of surface EMG during 2000 m rowing ergometry in trained rowers. Each participant performed three repeat laboratory testing sessions (S1, S2, S3) interspersed by 3–7 days between each session. Participants were asked to arrive at the laboratory in a hydrated state, which was confirmed upon arrival. In addition, participants were required to abstain from exercise on the day of testing and strength training in the 72 h before testing. Electrodes were attached to seven muscle sites for rowing specific EMG analysis [11–14] in accordance with procedures as described below within Table 1. Following this, participants completed a five-minute self-paced warm-up on a rowing ergometer, followed by a two-minute rest, before performing five maximal rowing power strokes on the rowing ergometer. After a subsequent five-minute rest period, the participants were then instructed to warm-up for a further five minutes on the rowing ergometer after, which they performed the 2000 m time-trial test.

Table 1 Description of EMG electrode placement locations and orientations used during the 2000 m test and power strokes [23]

Muscle	Location	Sensor orientation
Gastrocnemius (medialis)	On the most prominent bulge of the muscle	At a slight angle (approximately 15 degrees) to the longitudinal axis of the leg
Rectus abdominis	Electrodes were placed in a cephalad/caudad orientation at 2 cm inferior to the navel and 1 cm lateral to the midline	Vertical
Biceps femoris	The electrodes were placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia	In the direction of the line between the ischial tuberosity and the lateral epicondyle of the tibia
Gluteus maximus	Electrodes were placed at 50% on the line between the sacral vertebrae and the greater trochanter. This position corresponds with the greatest prominence of the middle of the buttocks well above the visible bulge of the greater trochanter	In the direction of the line from the posterior superior iliac spine to the middle of the posterior aspect of the thigh
Latissimus dorsi	The electrodes were placed 2 cm apart, approximately 4 cm distal to the inferior angle of the scapula	At an oblique angle of approximately 25 degrees
Erector spinae (longissimus)	The electrodes were placed at 4 cm lateral from the proc spinosus of L1	Vertical
Vastus medialis	Electrodes were placed at 80% on the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament	Almost perpendicular to the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament

Power strokes EMG normalization

Maximal stroke power, as well as the 2000 m test, was assessed using an air-braked rowing ergometer (Concept 2 Model C, Concept 2 Ltd, Wilford, Notts, UK) with a drag factor set at 140 (in accordance with the British International Rowing guidelines for ergometer testing) [16]. Following the five-minute self-paced warm-up, participants were provided a short break of two minutes and then returned to the ergometer to initially row sub-maximally for one minute, at which point they were instructed to perform two 'build up' strokes, followed by the first of five consecutive maximal effort power strokes. All participants were required to hold a rate of 30 s.min^{-1} during the power strokes, as described previously [17]. For each testing session, the mean rectified EMG recorded during the power strokes was used to normalize the mean rectified EMG recorded during the 2000 m test as subsequently detailed. This method is in accordance with the 'sprint method' of EMG normalization, which has seen to produce lower coefficient of variation values during subsequent repeated sessions in running and cycling compared to traditional MVC normalization [3, 4].

2000m Rowing ergometer test with surface EMG analysis

Following the power stroke test, participants were provided with a five-minute break and then returned to the ergometer. Participants performed a five-minute self-paced warm-up on the rowing ergometer before the initiation of each 2000 m test. During each session, the only feedback available to participants was the stroke rate and distance remaining [20]. Surface EMG was recorded from seven muscle sites; gastrocnemius, biceps femoris, gluteus maximus, erector spinae, vastus medialis, rectus abdominis and latissimus dorsi respectively (Table 1), and collected during 2000 m test at each visit. These muscles have been shown to contribute importantly to rowing performance [2, 11, 13, 14]. Surface EMG was collected at a sampling frequency of 1000 Hz and amplified (1000x) using a 16-channel wireless telemetric system (Myon RFTD-E16, Myon AG, Baar, Switzerland) interfaced with a multifunction data acquisition module (USB-6210, National instruments, Austin, Texas, USA). Site preparation and electrode placement were performed in accordance with the SENIAM guidelines [23] with exception of the rectus abdominis and latissimus dorsi for which procedures described by Ng et al. [24] and Horsley et al. [25] respectively were adopted. For each site, reduction in skin impedance was achieved prior to the attachment of the electrodes by shaving and cleaning the skin surface superior to the muscle belly with alcohol, followed by skin abrasion with a paper towel and then application of a standard electrode gel constituent [26]. Data were recorded within commercially available software (MyoResearch XP, Noraxon, Scottsdale, Arizona, USA) prior to being exported for analysis in LabChart (LabChart 7, AD Instruments, Oxford, UK). Once exported, the raw EMG data were high-pass-filtered with a cut-off frequency of 15 Hz, and the filtered data were fully rectified. On each testing occasion, mean rectified EMG recorded during each 500 m segment of the 2000 m test was normalized using the mean rectified EMG recorded during the power strokes. This was subsequently expressed as a percentage factor in relation to 1.0 (i.e., 1.0 = 100% of power strokes mean rectified EMG). EMG data were successfully collected from between 10 and 12 participants per muscle site per 2000 m session. Where 10 or 11 participants are listed in Tables 2–4, errors in data collection or data outliers were detected for 1 to 2 involved participants not included. This was due to electrodes being displaced during the 2000 m rowing test. Participants were identified as outliers using the 'mean ± three standard deviations' method [27]. Specifically, if a participant's mean EMG value over a 2000 m session was lesser or greater than the cohort mean EMG by three standard deviations, then the participant's data were excluded from the sample for that particular muscle.

Statistical analysis

Descriptive statistics are presented as mean (± standard deviation) unless otherwise stated. Statistical analyses were conducted using SPSS 25.0 (Chicago, IL, USA) with an alpha level set at $p < 0.05$. A one-way ANOVA was used to investigate between-sessions differences in 2000 m mean EMG for each of the seven muscle sites. Between-sessions (S1 to S2, S2 to S3) reliability and repeatability of EMG for the 2000 m test was measured by calculating coefficient of variation (CV) and intra-class correlation coefficient (ICC), both expressed with ± 90% confidence intervals [28]. CV descriptor categories for interpreting EMG reliability were adopted as defined by Kordi et al. [5] ('good' < 10%, 'acceptable' 10.0–19.9%, 'weak' 20.0–29.9% and 'very weak' ≥ 30.0%). Previously implicated correlation interpretations were adopted for ICC as follows; 'trivial' < 0.1, 'small' 0.1–0.29, 'moderate' 0.3–0.49, 'large' 0.5–0.69, 'very large' 0.7–0.89, 'almost perfect' 0.9–1.0 [5, 7]. The EMG data during the repeated sessions were further divided into four × 500 m segments (0–500 m, 500–1000 m, 1000–1500 m, 1500–2000 m). Subsequently, therefore, a three x four (session x segment) repeated measures ANOVA was used to investigate differences in each respective EMG output. Assumptions of sphericity were assessed using Mauchly's test of sphericity, with any violations adjusted by use of the Greenhouse–Geisser (GG) correction. If a significant main effect across time was shown, then post hoc differences across sessions were analyzed with use of the Bonferroni's correction.

Results

Power strokes

There were no significant differences identified in maximal power output for the power stroke test across sessions (S1: 529 ± 44 W, S2: 525 ± 45 W, S3: 524 ± 42 W) ($F_{2,11} = 0.049$,

Table 2 Mean ± SD for mean rectified EMG (uV) recorded for each muscle during the 'five power stroke' test with associated coefficient of variation, interclass correlation coefficient (± 90% CI) and CV rating for sessions 1–2, 2–3 and as a mean across all sessions

	$n =$	Session 1	Session 2	Session 3	CV% S1–S2	ICC S1–S2	CV% S2–S3	ICC S2–S3	CV% Mean	ICC Mean
Gastrocnemius	10	51.9 ± 21.2	38.0 ± 8.8	48.5 ± 30.0	35.6 (24.8–65.0) Very weak	0.13 (− 0.42 to 0.61)	31.7 (22.3–57.4) Very weak	0.27 (− 0.30 to 0.69)	33.7 (26.0–53.5) Very weak	0.38 (− 0.04 to 0.68)
Rectus abdominis	12	66.3 ± 15.1	64.9 ± 13.5	70.2 ± 17.0	12.0 (8.7–19.8) Acceptable	0.76 (0.42–0.91)	10.5 (7.7–17.2) Acceptable	0.84 (0.59–0.94)	11.3 (8.9–16.4) Acceptable	0.80 (0.60–0.91)
Biceps femoris	12	58.6 ± 14.9	55.3 ± 11.1	58.8 ± 16.3	21.2 (15.3–35.8) Weak	0.25 (− 0.32 to 0.65)	16.3 (11.8–27.1) Acceptable	0.51 (0.00–0.79)	18.8 (14.7–27.8) Acceptable	0.45 (0.07–0.71)
Gluteus maximus	10	50.8 ± 19.0	51.8 ± 20.0	46.5 ± 16.4	29.4 (20.7–52.9) Weak	0.68 (0.25–0.89)	26.9 (19.0–48.0) Weak	0.63 (0.16–0.87)	28.2 (21.9–44.5) Weak	0.61 (0.27–0.81)
Latissimus dorsi	11	142.4 ± 51.5	183.6 ± 91.9	111.2 ± 27.4	44.1 (30.5–82.4) Very weak	0.17 (− 0.45 to 0.62)	39.0 (27.1–71.8) Very weak	0.12 (− 0.49 to 0.59)	41.6 (32.0–67.3) Very weak	− 0.12 (− 0.53 to 0.30)
Erector spinae	10	81.5 ± 36.2	89.6 ± 44.1	87.3 ± 32.9	16.0 (11.3–29.0) Acceptable	0.90 (0.69–0.97)	15.7 (11.0–28.3) Acceptable	0.83 (0.53–0.94)	15.9 (12.1–24.3) Acceptable	0.84 (0.64–0.93)
Vastus medialis	10	177.7 ± 67.4	164.4 ± 29.5	184.0 ± 70.8	29.4 (20.3–55.4) Weak	0.42 (− 0.21 to 0.77)	32.5 (22.4–61.8) Very weak	0.04 (− 0.60 to 0.56)	31.0 (23.3–48.9) Very weak	0.37 (− 0.09 to 0.68)

$p = 0.953$). Reliability across power stroke sessions was high as indicated by mean CV (3.1%) and 'very large' mean ICC ($r = 0.87$). Reliability of EMG varied considerably across muscles with rectus abdominis, biceps femoris and erector spinae having 'acceptable' mean CV (11.3–18.8%), whereas for gluteus maximus, vastus medialis, gastrocnemius and latissimus dorsi mean CV ranged from 28.2 to 41.6% (Table 2).

Reliability of EMG during the 2000 m test

As we previously published elsewhere, there were no significant differences between-sessions for 2000 m performance time mean power or stroke rate [19]. There were no significant differences in mean rectified EMG muscle activation between-sessions for any of the seven muscles; gastrocnemius ($F_{2,9} = 0.460$, $p = 0.636$), biceps femoris ($F_{2,11} = 0.039$, $p = 0.962$), gluteus maximus ($F_{2,9} = 0.476$, $p = 0.627$), erector spinae ($F_{2,9} = 0.022$, $p = 0.979$), vastus medialis ($F_{2,9} = 2.068$, $p = 0.146$), rectus abdominis ($F_{2,11} = 1.762$, $p = 0.188$) and latissimus dorsi ($F_{2,10} = 1.116$, $p = 0.341$) (Table 3). Mean CV for six out of the seven EMG muscle sites was 'acceptable' (12.3–18.6%); however, for gastrocnemius, CV was classed as 'weak' (28.6%). Mean ICC values across EMG muscle sites were 'very large' ($r = 0.75$–0.89) for erector spinae, gluteus maximus and rectus abdominis, 'large' ($r = 0.57$–0.63) for vastus medialis and biceps femoris, and moderate ($r = 0.31$–0.35) for gastrocnemius and latissimus dorsi.

EMG across 4 × 500 m segments of the 2000 m test

The CV for mean rectified EMG across the seven muscles for each 500 m segment of the 2000 m test is shown in Table 4. Latissimus dorsi displayed the lowest mean CV for rectified EMG across each 500 m segment of the 2000 m time session (12.4–15.4%) and gastrocnemius showed the highest (27.7–31.4%). There were significant within-session differences across session segments for biceps femoris EMG ($F(\mathrm{GG})_{2,11} = 4.921$, $p = 0.029$) whereby activation was significantly greater during 1500–2000 m (0.72 ± 0.14) in comparison to 1000–1500 m (0.65 ± 0.11) ($p = 0.009$). For gluteus maximus ($F(\mathrm{GG})_{2,9} = 13.276$, $p = 0.001$), activation was significantly greater during 1500–2000 m (0.59 ± 0.16) in comparison to 500–1000 m (0.53 ± 0.16) ($p = 0.002$), and 1000–1500 m (0.53 ± 0.16) ($p = 0.001$). For vastus medialis ($F(\mathrm{GG})_{2,9} = 11.985$, $p = 0.002$), activation was significantly greater during 0–500 m (0.57 ± 0.09) than 500–1000 m (0.49 ± 0.09) ($p = 0.002$) and 1000–1500 m (0.49 ± 0.10) ($p = 0.013$). Vastus medialis activation was also significantly greater during 1500–2000 m (0.57 ± 0.14) compared to 500–1000 m ($p = 0.023$) and

Table 3 Mean ± SD for normalized EMG during 2000 m rowing ergometry (expressed as a factor of power strokes mean rectified EMG) with associated coefficient of variation and interclass correlation coefficient (±90% CI) and CV rating for sessions 1–2, 2–3 and as a mean across all sessions

Muscle	$n =$	Session 1	Session 2	Session 3	CV% S1–S2	ICC S1–S2	CV% S2–S3	ICC S2–S3	CV% Mean	ICC Mean
Gastrocnemius	10	0.66 ± 0.32	0.70 ± 0.16	0.68 ± 0.12	39.0 (27.1–71.9) Very weak	0.15 (−0.40 to 0.63)	14.3 (10.2–24.6) Acceptable	0.65 (0.19–0.87)	28.6 (21.7–42.8) Weak	0.35 (−0.08 to 0.65)
Rectus abdominis	12	0.70 ± 0.18	0.61 ± 0.14	0.59 ± 0.14	16.3 (11.6–28.2) Acceptable	0.65 (0.26–0.86)	10.7 (7.7–18.3) Acceptable	0.87 (0.68–0.95)	13.8 (10.6–20.1) Acceptable	0.75 (0.53–0.88)
Biceps femoris	12	0.69 ± 0.11	0.68 ± 0.09	0.69 ± 0.19	9.5 (6.9–16.1) Good	0.58 (0.15–0.83)	18.7 (13.3–32.6) Acceptable	0.48 (0.01–0.78)	14.7 (11.3–21.5) Acceptable	0.57 (0.26–0.78)
Gluteus maximus	10	0.56 ± 0.17	0.51 ± 0.18	0.58 ± 0.19	16.5 (11.8–28.5) Acceptable	0.80 (0.47–0.93)	20.6 (14.6–36.0) Acceptable	0.83 (0.54–0.94)	18.6 (14.2–27.4) Acceptable	0.78 (0.56–0.90)
Latissimus dorsi	11	0.69 ± 0.10	0.70 ± 0.08	0.75 ± 0.10	13.1 (9.5–21.6) Acceptable	0.23 (−0.30 to 0.66)	11.5 (8.4–19.0) Acceptable	0.32 (−0.21 to 0.71)	12.3 (9.7–18.0) Acceptable	0.31 (−0.10 to 0.61)
Erector spinae	10	0.59 ± 0.21	0.57 ± 0.18	0.56 ± 0.18	9.4 (6.8–16.0) Good	0.96 (0.87–0.99)	19.2 (13.7–33.6) Acceptable	0.83 (0.55–0.94)	15.0 (11.5–21.9) Acceptable	0.89 (0.75–0.95)
Vastus medialis	10	0.59 ± 0.12	0.50 ± 0.06	0.50 ± 0.15	10.4 (7.4–17.6) Acceptable	0.60 (0.12–0.86)	16.4 (11.7–28.3) Acceptable	0.54 (0.03–0.83)	13.6 (10.5–19.9) Acceptable	0.63 (0.30–0.81)

Table 4 Coefficient of variation (±90% CI) for sessions 1–2, 2–3 and mean across all sessions for normalized EMG during successive 500 m segments of the 2000 m ergometer test for seven muscles

Muscle	*n*=	Segment	CV S1–S2 (%)	CV S2–S3 (%)	Mean CV (%)
Gastrocnemius	10	0–500 m	42.3 (29.3–78.7)	15.9 (11.4–27.5)	31.1 (23.9–48.8)
	10	500–1000 m	36.9 (25.7–67.6)	15.6 (11.2–26.9)	27.7 (21.4–43.2)
	10	1000–1500 m	41.7 (29.0–77.5)	18.1 (12.9–31.4)	31.4 (24.1–49.4)
	10	1500–2000 m	38.7 (27.0–71.4)	12.8 (9.2–22.0)	28.0 (21.6–43.7)
Rectus abdominis	12	0–500 m	13.9 (10.2–22.4)	12.5 (9.2–20.1)	13.2 (10.4–18.6)
	12	500–1000 m	19.3 (14.1–31.4)	11.8 (8.7–18.9)	15.9 (12.6–23.2)
	12	1000–1500 m	15.2 (11.1–24.5)	12.9 (9.5–20.7)	14.1 (11.1–20.8)
	12	1500–2000 m	14.9 (10.9–24.0)	13.9 (10.2–22.4)	14.4 (11.4–20.8)
Biceps femoris	12	0–500 m	10.9 (8.1–17.5)	18.5 (13.5–30.0)	15.1 (11.8–21.3)
	12	500–1000 m	14.4 (10.6–23.1)	17.4 (12.8–28.3)	16.0 (12.5–22.6)
	12	1000–1500 m	11.9 (8.8–19.1)	16.2 (11.9–26.3)	14.2 (11.2–20.0)
	12	1500–2000 m	8.6 (6.4–13.7)	19.0 (13.9–30.9)	14.6 (11.4–20.6)
Gluteus maximus	10	0–500 m	19.2 (13.7–33.5)	23.0 (16.3–40.6)	21.2 (16.2–31.3)
	10	500–1000 m	11.6 (8.3–19.8)	25.1 (17.7–44.5)	19.3 (14.7–28.4)
	10	1000–1500 m	17.3 (12.3–29.9)	20.8 (14.8–36.4)	19.1 (14.6–28.1)
	10	1500–2000 m	21.7 (15.4–38.2)	19.6 (14.0–34.3)	20.7 (15.8–30.6)
Latissimus dorsi	11	0–500 m	17.6 (12.6–30.6)	12.9 (9.2–22.1)	15.4 (11.8–22.5)
	11	500–1000 m	13.9 (10.0–23.9)	10.8 (7.7–18.3)	12.4 (9.6–18.1)
	11	1000–1500 m	12.1 (8.7–20.7)	12.8 (9.2–21.9)	12.5 (9.6–18.1)
	11	1500–2000 m	15.7 (11.2–27.2)	14.9 (10.7–25.7)	15.3 (11.8–22.4)
Erector spinae	10	0–500 m	8.5 (6.1–14.3)	13.3 (9.5–22.8)	11.1 (8.6–16.1)
	10	500–1000 m	9.7 (7.0–16.5)	19.8 (14.1–34.6)	15.4 (11.9–22.6)
	10	1000–1500 m	13.0 (9.4–22.4)	23.6 (16.7–41.8)	18.9 (14.5–27.9)
	10	1500–2000 m	14.1 (10.1–24.2)	24.6 (17.4–43.6)	19.9 (15.2–29.3)
Vastus medialis	10	0–500 m	13.8 (9.9–23.7)	16.3 (11.6–28.2)	15.1 (11.6–22.1)
	10	500–1000 m	10.5 (7.6–17.9)	17.9 (12.6–30.6)	14.4 (11.1–21.1)
	10	1000–1500 m	9.9 (7.2–16.9)	18.4 (13.1–32.1)	14.7 (11.3–21.5)
	10	1500–2000 m	12.6 (9.0–21.5)	16.8 (12.0–29.0)	14.8 (11.4–21.6)

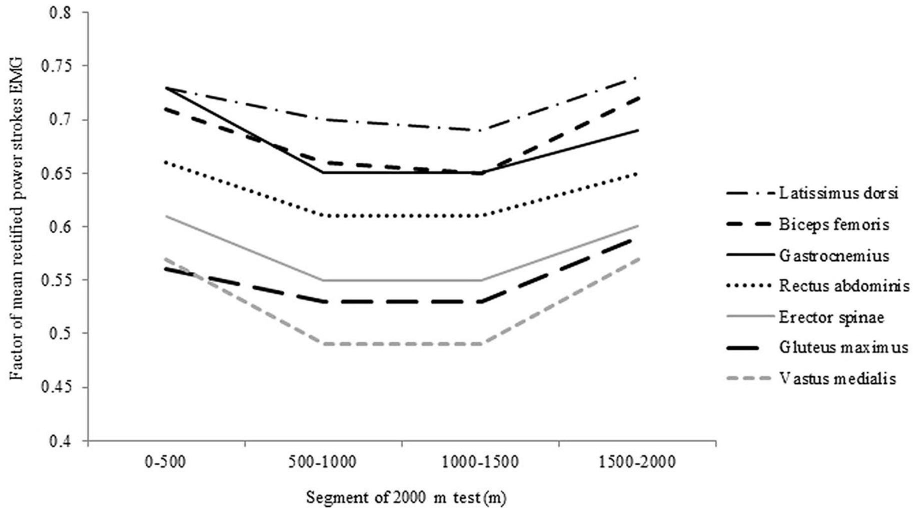

Fig. 1 Serial pattern of EMG for all seven muscles. EMG for each 500 m segment is expressed as a factor of the mean rectified EMG value recorded across the five power strokes. The mean values for the three 2000 m sessions are shown per 500 m stage segment for each site

1000–1500 m ($p = 0.006$). In relation to mean values for all seven muscles across segments of the 2000 m test, the pattern was for a decrease in EMG amplitude during 500–1000 m and 1000–1500 m compared to 0–500 m and 1500–2000 m (Fig. 1). There were no between-sessions 500 m segment differences in EMG at any of the muscle sites ($p > 0.05$).

Discussion

This is the first study to the authors' knowledge, to assess the reliability of surface EMG across repeated 2000 m rowing ergometer sessions. The mean CV (composite of S1 to S2 and S2 to S3) for rectified EMG during the 2000 m test across the seven muscles ranged from 12.3 to 28.6%. However, it is important to note that an 'acceptable' CV for mean rectified EMG (12.3–18.6%) was observed at six of the seven muscles; rectus abdominis, biceps femoris, gluteus maximus, latissimus dorsi, erector spinae, vastus medialis [5]. In addition, for five of the seven muscles, EMG mean ICC repeatability across sessions was interpreted as 'large' and 'very large' (0.57–0.89) [5, 7]. The observed CV values for mean rectified EMG (12.3–28.6%) are generally lower than reported during sprint cycling where normalized EMG values were most often reported to be 'weak' (CV = 20–29.9%) [5]. However, our study's obtained values are more aligned with summative CV values as reported from six muscles during a five-minute cycling time-trial (CV = 14–21%) [3]. Interestingly, obtained EMG CV values were also similar to those recorded across six different lower body muscles (CV = 15–20%) during an incremental running test, which utilized a similar 'sprint' method of normalization (20 m run sprint) as was implemented in the current study (power strokes) [4]. In relation to previous investigations that have assessed EMG during rowing, our results are generally in correspondence with Guével et al. [11] (ICC = 0.61–0.98) and Bazzucchi et al. [12] (ICC = 0.74–0.93) who reported moderate to good reproducibility in EMG activation patterns during various component segments of a single on-water training session and a series of 1000 m time sessions performed on the ergometer and on-water respectively.

When investigating within-session EMG activation rates in respect to the four × 500 m component segments of the 2000 m, there were some significant differences. Mean rectified EMG of the vastus medialis was greater during 0–500 m and 1500–2000 m, compared with 500–1000 m and 1000–1500 m. Values for biceps femoris and gluteus maximus were significantly higher during 1500–2000 m in comparison to 500–1000 m and 1000–1500 m. The general pattern of higher activation rates during 0–500 m and 1500–2000 m in comparison to 500–1000 m and 1000–1500 m, is reflected within mean values for each observed muscle (Fig. 1). However, seemingly the observed EMG sensitivity, negated further significance being represented across all assessed muscles in respect to test segments. In relation to within-session EMG values, it is interesting to note the similarity of mean values for each muscle during 0–500 m and 1500–2000 m. This is despite 0–500 m being performed at a significantly greater mean power output compared to 1500–2000 m, which we previously reported for the featured cohort [19]. This indicates that despite similar conscious effort and neural activation between 0–500 m and 1500–2000 m, the inherent fatigue within the exercising musculature, reduced the obtainable power output of the participants during the final stages of the session [29].

In respect to our previous reported findings assessing the consistency of pacing and power output during 2000 m, we described significant differences in power output in respect to 0–500 m and 1500–2000 m between S1 compared to S2 and S3 [19]. However, as shown within the current article, there were no differences in EMG during any 500 m segment between-sessions. With respect to the change in pacing strategy following S1, where participants consciously produced a lower power output in 0–500 m during S2 and S3 [19], it could have been predicted that a lower neural drive would have accompanied this self-regulated reduction in power [13]. The level of variability of EMG during the repeated 2000 m sessions (mean CV = 12.3–28.6%), may have negated such changes from being displayed. As previously discussed, in terms of between-session EMG reliability of locomotive exercise, our obtained values were generally at the previously defined 'acceptable' level (CV = 10–20%) [3–6]. However, this level of sensitively was seemingly not sufficient to observe potential differences in neural activation rates, which would potentially correspond to the small but significant changes in power output (4–6%) as previously described across 500 m segments of the three sessions [19].

The findings of this study indicated that surface EMG values were shown to be generally at the 'acceptable' level in relation to reliability over repeated 2000 m sessions performed during three separate visits. However, EMG was seemingly not sensitive enough to identify potential changes in neural activation between-sessions, whereby previously reported significant changes in pacing strategy occurred in respect to observable power output during repeated 2000 m. Therefore, caution should be taken when interpreting EMG values in respect to small but significant changes within pacing during 2000 m rowing.

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Availability of data and material The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability N/A.

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

Ethical approval Approval was obtained from the ethics committee of Northumbria University. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication The participants consented to the submission of the research to an academic journal.

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