Thigh Muscle Activities in Elite Rowers During On-Water Rowing

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Key words
- surface electromyography
- muscular activation pattern
- quadriceps
- hamstring

Abstract

This study analysed the muscle activity levels and patterns of the major thigh muscle activation during training sections at different intensities of on-water rowing. 9 experienced rowers performed 2 imposed-pace sections (B1 and B2) and 2 maximal-speed sections (start, 500 m) of on-water rowing. The knee angle, power output, mean torque and stroke rate were measured using specific instrumentation and were synchronised with surface electromyography signals of 5 superficial quadriceps and hamstring muscles. B1 and B2 sections were not significantly different regarding mechanical parameters and EMG activities, while the start phase induced large differences. The EMG patterns for B1, B2 were similar (cross-correlation coefficients (CC) ranged between 0.972–0.984) and the moderate CC found between both B1 and start (0.605–0.720) and B2 and start (0.629–0.720). Our results suggest that the hamstring muscles have a motor action and contribute to the power production during the leg drive. During an all-out 500 m section, a decrease in power and stroke rate was found (up to 20 %). However, EMG patterns were not time shifted for all muscles. During the leg drive, the muscle activity levels of the quadriceps muscles were unchanged, while the activity of the hamstring muscles decreased.

Introduction

Rowing is an Olympic discipline which requires a high level of physical preparation. In competition, rowers must row 2 000 m as fast as possible (5 min 30 s to 8 min, depending on the boat and gender). The physiological and biomechanical stress resulting from rowing has been widely explored [9, 17, 26]. The power produced at each oar stroke seems to be a determining factor of performance in rowing. The rowing power reaches 300–450 W on average over 2 000 m and 600–700 W in the start phase [29, 30]. In this global power production, both hip and knee extensions are very important [27]. Thus, the forces applied to the handle and to the foot stretchers by high level rowers on the ergometer reach 1 100 N and 1 000 N, respectively [3, 21, 29]. In on-water rowing, the stretcher force could be 40 % higher than the handle force due to different mechanics [15]. In addition, it has been demonstrated that the maximal force and muscular power were greater in knee extensors and hip extensors-flexors in rowers, compared with non-practicing subjects with similar morphological characteristics [24]. In addition, quadriceps muscles are thought to constitute the "driving" elements at the source of the power generated by the elite rower [7, 25, 31].

Activity levels and muscle activation patterns of the muscles crossing the knee joint have been investigated during rowing on an ergometer. It appears that the superficial quadriceps muscles take part in different ways during the rowing action. These chronological differences can be explained by their respective functional role (*vastus lateralis* and *medialis*: extensor muscles of the leg and locker of the knee joint; *rectus femoris*: extensor muscle of the leg and flexor of the trunk) [14, 31]. The *vastus lateralis* and *vastus medialis* are the most solicited during the initial phase of the knee extension, whereas the *rectus femoris* is used mainly at the end of the extension [16, 25]. The latter is particularly active as a brake during the trunk extension phase. Furthermore, knee flexors and hip extensors (*biceps femoris, semitendinosus*) are active at the end of the knee extension and play an active role in the hip extension of a closed chain movement [13, 14, 21].

accepted after revision
September 28, 2010

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DOI http://dx.doi.org/10.1055/s-0030-1268412
Published online: November 25, 2010
Int J Sports Med 2011; 32: 109–116 © Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

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In France, on-water training mainly includes sections at moderate intensity (65% HR_{max} < Heart Rate (HR) < 85% HR_{max}, 16–20 strokes.min^{-1}, duration: 2 × 20–40 min) in comparison to the all-out 2 000 m performed during competitions (HR about: 95% HR_{max}; stroke rate about: 35 strokes.min^{-1} [10, 22]). Due to muscular redundancy, it has been demonstrated that a power output increase induces changes in the level of muscular activity depending on the muscle during pedalling [13] and running [28]. This suggests that muscular compensations would appear during the different training sections performed by high levels rowers. In addition, it should be expected that rowing at a racing pace would induce high levels of muscle fatigue that may also affect muscular coordination as suggested during pedalling [5]. The aim of this study was to examine the muscle activity levels and patterns of muscle activation of the major thigh muscles during training sections at different intensities of on-water rowing training and a maximal exercise over 500 m.

Methods

Subjects

9 rowers, 5 men (23 ± 2 years, 79.9 ± 14.8 kg, 185.8 ± 4.0 cm, 4 lightweights and 1 heavyweight) and 4 women (23 ± 2 years, 67.1 ± 6.5 kg, 176.3 ± 6.3 cm, 1 lightweight and 3 heavyweights) volunteered to participate in the present study. All participants were at least at French national level and trained daily, approximately 14 ± 2 h per week, at the time of the study. All participants had performed an all-out 2 000 m rowing test (6:27 ± 0:13 min:s for the males and 7:18 ± 0:11 min:s for the females) on a fixed rowing ergometer (Concept 2 system, Model C, Morrisville, VT, USA) in the same year of this experiment. None of the subjects presented pain or injury that would prevent participation in the present study. Each subject was clearly informed of the purpose of the study before his written consent was obtained. This study was conducted according to the Helsinki Statement (last modified in 2004) and has been approved by the local ethics committee and is in accordance with the IJSM ethical standards [11].

Material

Bipolar electromyographic (EMG) activity was measured with surface electrodes (4-mm diameter Ag-AgCl, In Vivo Metric, Healdsburg, CA) that were placed, according to Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations [12], over the *rectus femoris* (RF), *vastus lateralis* (VL), *vastus medialis* (VM), *biceps femoris* (BF), *semitendinosus* (ST) dominant side muscles. Interelectrode distance was set at 20 mm. Electrodes were placed longitudinally with respect to the underlying muscle fibre arrangement, distal to the motor point. Reference electrodes were placed over the lateral and medial condyles of the tibia. Prior to electrode placement, the skin was shaved and cleaned with alcohol in order to reduce electrode-skin impedance below 55 kΩ. Then, EMG signals were preamplified (gain = 600, bandwidth 6–400 Hz) and sampled at 1 024 Hz with a 12-bit A/D converter (Myodata Compact, Electronique du Mazet, Le Mazet Saint Voy, France; input impedance = 10 GΩ; common mode-rejection ratio at 50/60 Hz = 100 dB; sampling frequency = 0–400 Hz).

Rowers' personal skiffs were equipped in order to measure the power produced by rowers as described in previous studies [1]. Firstly, a one turn calibrated potentiometer (6639S, Bourns, USA) was fixed on the port rigger (**Fig. 1**), and coupled with the oarlock, in order to measure oar angular position [1]. Zero degree corresponded to the oar perpendicular to the boat, with positive angles indicating a displacement of the oar handle towards the bow of the shell. In order to measure the torque applied on the oarlock, the port oar (Concept 2, Morrisville, VT, USA) was instrumented [1]. 2 axial strain gauges (LY1x, HBM, Germany) were glued on the oar between the collar and the blade perpendicular to the plane of the blade (**Fig. 1**), and connected to a 1/2 Wheatstone bridge. Thus, the output voltage of the 1/2 Wheatstone bridge was proportional to the torque applied on the oarlock. Finally, the output voltage was calibrated with static 3 point bending tests to measure the torque applied on the oarlock. The mean power per stroke was then calculated as the mean of the torque applied to the oarlock and the oar angular velocity [1]. In addition, an electrogoniometer (SG150, Biometrics Ltd, UK) [17] was used to measure knee angle (**Fig. 1**). 180° corresponded to a full extension and negative variations indicated knee flexion. Knee angle, oar angle and torque were sampled at 128 Hz with the 12-bit A/D converter (Myodata Compact, Electronique du Mazet, Le Mazet Saint Voy, France). Mechanical (oar torque, oar angle and knee angle) and EMG data were stored in a flash memory card (20 MB) and transferred to a computer hard disk for further analysis.

Protocol

After a period of EMG preparation (10 min), the acquisition system was made watertight and placed in the subjects' personal skiffs (**Fig. 1**). The on-water period (50 min) was composed of 5 sections separated by 5 min of rest. *i*) A warm-up session of 5 min; *ii*) 10 min of a training section called B1 performed at a

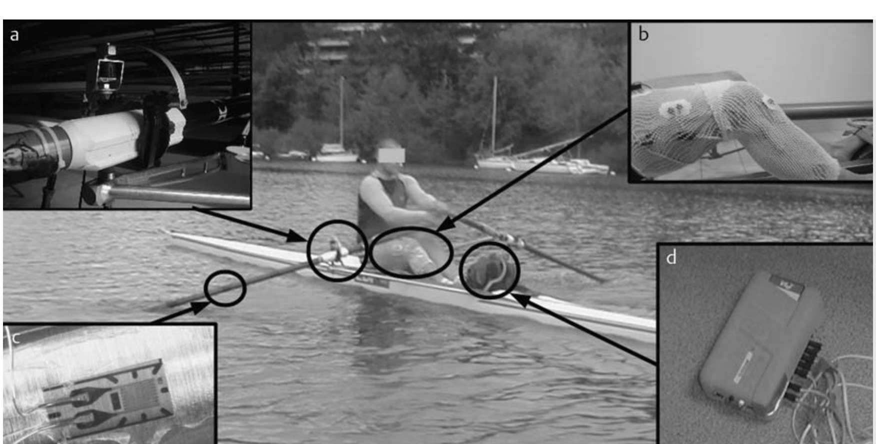

Fig. 1 Equipment of the rower and the boat for the experiments. **a**- A potentiometer was placed on the port oarlock to measure oar angle. **b**- Surface electromyographic electrodes were placed on superficial muscles of the right thigh. The knee angle was also measured using an electrogoniometer. **c**- 2 strain gauges were glued on the port oar and calibrated in order to measure the torque produced by the rower at the oarlock. **d**- All signals were sampled using a portable and watertight analogic/digital converter and stored on a flash drive for further analysis.

rate of 65% HR_{max} < HR < 75% HR_{max}, and 16–18 strokes.min^{-1}; *iii*) 10 min of a training section called B2 performed at a rate of 75% HR_{max} < HR < 85% HR_{max}, and 18–20 strokes.min^{-1}; *iv*) 2 maximal starts (15 strokes); *v*) an all-out 500 m. HR_{max} was measured during a graded maximal exercise test on rowing ergometer. During these sections, rowers monitored their heart rate using their own equipment in order to reproduce paces performed during training sessions. Data were recorded continually during the on-water sessions, but due to a limitation of the flash memory card, only the 7 first minutes of the B1 and B2 sections were recorded.

Data analysis

The data processing was performed using standardized Matlab scripts (The Mathworks, Natick, USA). A Butterworth second order low pass (10 Hz) was applied to the raw mechanical signals (oar torque, oar angle and knee angle). The mean power, the mean torque, and the stroke rate (using the oar angle) were calculated for each stroke. To calculate electromyographic patterns (i.e., EMG activity level across the cycle) each stroke was separated in a propulsion phase starting at the minimum of the knee angle and finishing at the maximum of the oar angle, and a recovery phase starting at the maximum of the oar angle and finishing at the following knee angle minimum (**Fig. 2**). Propulsion and recovery phases were divided into 50 equal periods of time and the EMG root mean square (RMS) was calculated for each period in order to obtain EMG patterns. Afterwards, the mean EMG activity was calculated as the mean RMS value across the cycle. EMG patterns were then normalized using this mean EMG activity level obtained during the B1 section. A mean EMG activity level was also calculated during the leg drive phase starting from the minimum of the knee angle and finishing at 165° of knee angle (**Fig. 2**).

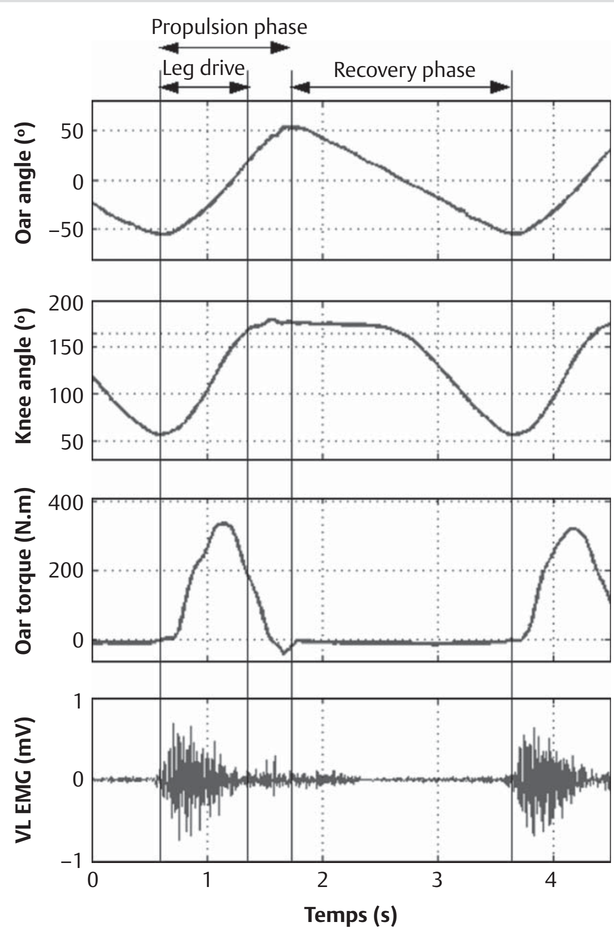

Fig. 2 Phases of the rowing stroke considered for the data analysis. The propulsion (drive) phase started at the minimum of the knee angle and finished at the maximum of the oar angle. The leg drive and recovery phases finished at 165° of knee angle and at the next minimum of the knee angle.

To compare the training sections, EMG patterns (i.e., EMG activity level across the cycle), mean EMG activity level (i.e., calculated during the whole drive phase and during the leg drive) and mean mechanical parameters (i.e., stroke rate, power and mean torque) were determined during the third minute of B1 and B2, and during the 10 last strokes of the second start. To assess the changes during the all-out 500 m, it was divided in 4 equal time periods, and all the parameters were averaged on these 4 quarters.

Statistical analysis

After checking the normality of data distribution (Kolmogorov-Smirnov test), parametric statistical tests were performed using Statistica software (Statsoft Inc.). Repeated (1 × 3) measures analyses of variance (ANOVAs) were used to determine changes in mean EMG during the whole stroke (5 muscles), mean EMG during the leg drive (5 muscles), mean power, mean torque and stroke rate across the 3 training sections (B1, B2 and start). ANOVAs (1 × 4) were also performed to assess changes in the same parameters between the 4 quarters of the maximal exercise over 500 m. Fisher's least significant difference (LSD) post-hoc analyses were performed when appropriate. The critical level of significance in the present study was set at $p \leq 0.05$.

Cross-correlation was used to measure the relative change in the temporal characteristics of neuromuscular activity [6,32]. In addition, the cross-correlation coefficients of EMG RMS curves for each muscle were calculated with a zero time lag.

Results

Due to experimental problems (i.e., electrodes detachment), the data of RF and BF muscles of 2 subjects were not used, and therefore results presented for these 2 muscles were obtained on 7 subjects.

Comparison of training sections at different intensities

Averaged mechanical parameters are provided in **Table 1**. Mean power and mean torque were not significantly different between B1 and B2, while these parameters were significantly higher during the start than during B1 and B2. For the comparison between B1 and B2, the stroke rate parameter was significantly ($p = 0.05$) higher during B2 than during B1. The EMG patterns for B1, B2 and the start are shown in **Fig. 3**. Very high cross-correlation coefficients were found for all muscles between B1 and B2 (ranged from 0.972–0.984, depending on the muscle chosen), indicating that the shape of the EMG patterns were very similar between these 2 intensities. On the contrary, moderate cross-correlation coefficients were found between both B1 and start (ranged from 0.605–0.720) and B2 and start (ranged from 0.629–0.720) indicating that the shape of the EMG patterns changed between the start and B1/B2. In addition, EMG patterns were not time shifted for VL (between 0.1 and 0.4%), VM (between 0.1 and 0.2%) and RF (between 0.0 and 1.7%). The time shift was

Table 1 Mechanical parameters for the 3 training sections.

	stroke rate (stroke/min)			mean power (W)			mean force (N.m)		
	B1	B2	Start	B1	B2	Start	B1	B2	Start
mean	17.9	19.6	39.5	216.1	242.4	592.4	110.7	121.6	238.0
sd	0.7	0.6	3.3	52.6	53.8	179.3	24.0	22.4	57.5
main effect		***			***			***	
B1 vs. B2		*			ns			ns	
B2 vs. Start		***			***			***	
B1 vs. Start		***			***			***	

B1, B2 and start: different training sequences at different exercise intensity. *: $p<0.05$, ***: $p<0.001$, ns: $p>0.05$

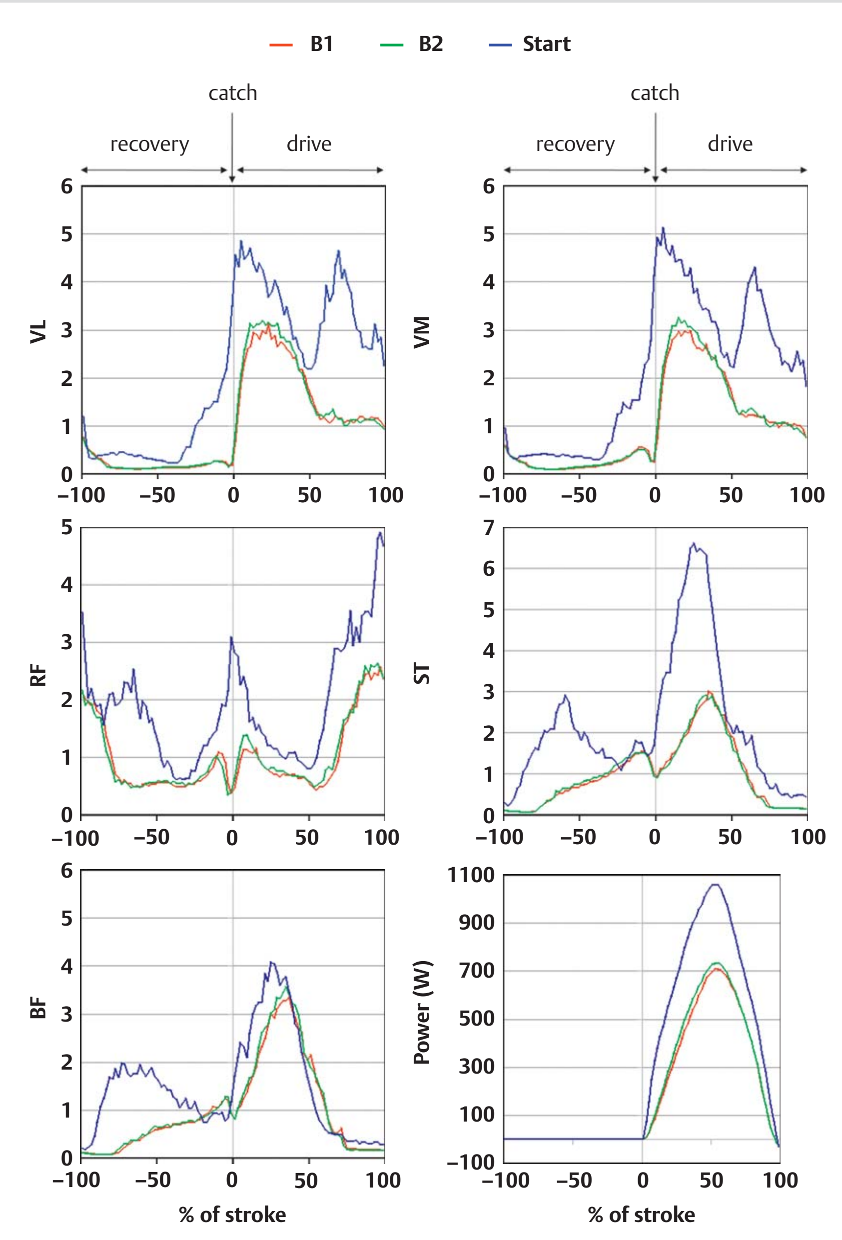

Fig. 3 Electromyographic patterns averaged across subjects, normalized with the mean EMG activity for the B1 and power during the training sections, and expressed in percentage of the recovery and drive phases. B1, B2 and start: training sections at different exercise intensity. VL: *vastus lateralis*, VM: *vastus medialis*, RF: *rectus femoris*, ST: *semitendinosus*, BF: *biceps femoris*.

higher for ST (B1 vs. B2: 0.4±0.5%, B1 vs. start: 5.1±4.1%, B2 vs. start: 4.7±4.0%) and BF (B1 vs. B2: 0.4±0.5%, B1 vs. start: 3.6±2.0%, B2 vs. start: 3.6±2.4%). This indicates that the EMG activity of the hamstrings was shifted backwards as the power increased (▶ **Fig. 3**). For all muscles and both for the whole cycle and the leg drive, EMG activity levels were not significantly different between B1 and B2, while they were significantly higher during the start than during B1 and B2 (▶ **Table 2**).

Maximal exercise over 500 m

Statistical analyses showed significant decreases in all the mechanical parameters (stroke rate, mean torque and mean power, ▶ **Fig. 4**) during the 500 m. The EMG patterns for the 4

Table 2 B2 and start sections electromyographic activity levels averaged during the whole stroke cycle and during the leg drive phase. sEMG activity levels are expressed in percentage of values obtained during the B1 section.

		VL		VM		RF		ST		BF	
		B2	**Start**	**B2**	**Start**	**B2**	**Start**	**B2**	**Start**	**B2**	**Start**
whole cycle	**mean**	103.8 %	210.4 %	103.2 %	207.9 %	102.8 %	188.3 %	100.5 %	219.8 %	103.0 %	149.0 %
	sd	15.1 %	105.9 %	14.6 %	78.6 %	8.2 %	36.6 %	9.5 %	83.8 %	9.8 %	47.5 %
	main effect	**		***		**		**		***	
	B1 vs. B2	ns		ns		ns		ns		ns	
	B2 vs. Start	**		***		**		**		**	
	B1 vs. Start	***		***		**		**		**	
leg drive	**mean**	109.6 %	168.6 %	110.0 %	177.6 %	116.1 %	243.3 %	101.1 %	254.1 %	107.9 %	138.3 %
	sd	11.4 %	51.4 %	8.3 %	14.5 %	13.0 %	98.9 %	10.8 %	89.3 %	11.0 %	49.8 %
	main effect	***		***		**		**		**	
	B1 vs. B2	ns		ns		ns		ns		ns	
	B2 vs. Start	**		***		**		***		**	
	B1 vs. Start	*		***		**		***		*	

B1, B2 and start: different training sequences at different exercise intensity. VL: *vastus lateralis*, VM: *vastus medialis*, RF: *rectus femoris*, ST: *semitendinosus*, BF: *biceps femoris*. *** : $p<0.001$, ** : $p<0.01$, * : $p<0.05$, ns: $p>0.05$

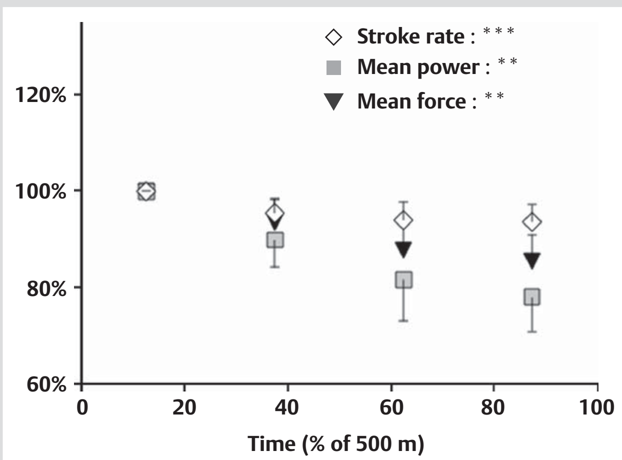

Fig. 4 Changes in mechanical parameters expressed in % of initial values during the all-out 500 m. ** , *** : significant main effect of time and significant difference ($p<0.01$, $p<0.001$, respectively) between the first quarter and the 3 other quarters.

quarters of the 500 m are shown in ▶ **Fig. 5**. Very high cross-correlation coefficients were found for all muscles (ranged from 0.904–0.983). In addition, the results showed that the EMG patterns were not time shifted (from 0.0–0.6 %). The main finding was that the EMG activity level was decreased for VL and VM muscles in the second part of the propulsion phase. Statistical analyses showed significant decreases in mean EMG activity of VL, VM muscles during the whole stroke, of ST and BF muscles during both the whole stroke and the leg drive (▶ **Fig. 6**). No significant change in mean EMG activity level was found for VL and VM muscles during the leg drive and for the RF muscle during both the whole cycle and the leg drive (▶ **Fig. 6**).

Discussion
▼

The present study reported the muscle activity levels and patterns of the major thigh muscles during training sections of on-water rowing. Only the start phase (maximal intensity) showed differences in muscular activity. During an all-out 500 m section, a decrease in power and stroke rate was found. These mechanical changes were not associated with changes in muscle activation patterns. During the leg drive, the muscle activity levels of the quadriceps muscles were unchanged, while the activity of the hamstring muscles decreased during the all-out 500 m.

Methodological considerations
Since rowing is a complex multi-joint task involving numerous major muscle groups (e.g., crossing ankle, knee, hip, low back, shoulder, elbow and wrist), the number of muscles (only those crossing the knee joint) investigated in the present study may be limited. However, this study was the first study to perform on-water rowing measurements and so further work will be required to thoroughly study the muscle synergies during rowing. The hip and knee extensors investigated in this on-water study were identified as the primary elements of the power produced by the high-level rowers [7, 14, 25, 30].

A classical methodological problem in EMG studies concerns the normalization of sEMG signals [2, 4, 13]. In the present study the normalization was not required since intra-session and intra-subject comparisons were performed. A normalization procedure with the corresponding activity assessed during the B1 section was achieved only to compare the pattern shapes (▶ **Fig. 3, 5**), and the sEMG activities were averaged across subjects (▶ **Table 2**). This analysis did not quantify the muscle activity levels in regard to the maximal voluntary contraction; therefore, it is not possible to discuss the actual muscle solicitations without further data analysis. Considering the limits of this procedure, a complementary approach was used to normalise muscle activity levels. The sEMG activities were normalized with maximal activities recorded during maximal isometric knee extension in closed chain movement performed on an equipped ergometer (Dyno, Concept 2 Morrisville, VT, USA) at 3 different knee angles (90°, 110°, 130°; 180° = full knee extension). The maximal activity level during each stroke was normalized with the maximal activity level reached at the closer knee angle. Using this normalization procedure, sEMG activities of VL and VM muscles reached respectively 42 ± 10 % of MVIC and 47 ± 13 % for B1, 45 ± 11 % and 51 ± 13 % for B2, and 60 ± 21 % and 73 ± 26 % for the start section, indicating high levels of solicitation of these during the studied on-water training sections. The muscle activity levels were quite lower for the RF muscle (7 ± 4 %, 9 ± 5 % and 17 ± 7 % for B1, B2 and start sections, respectively).

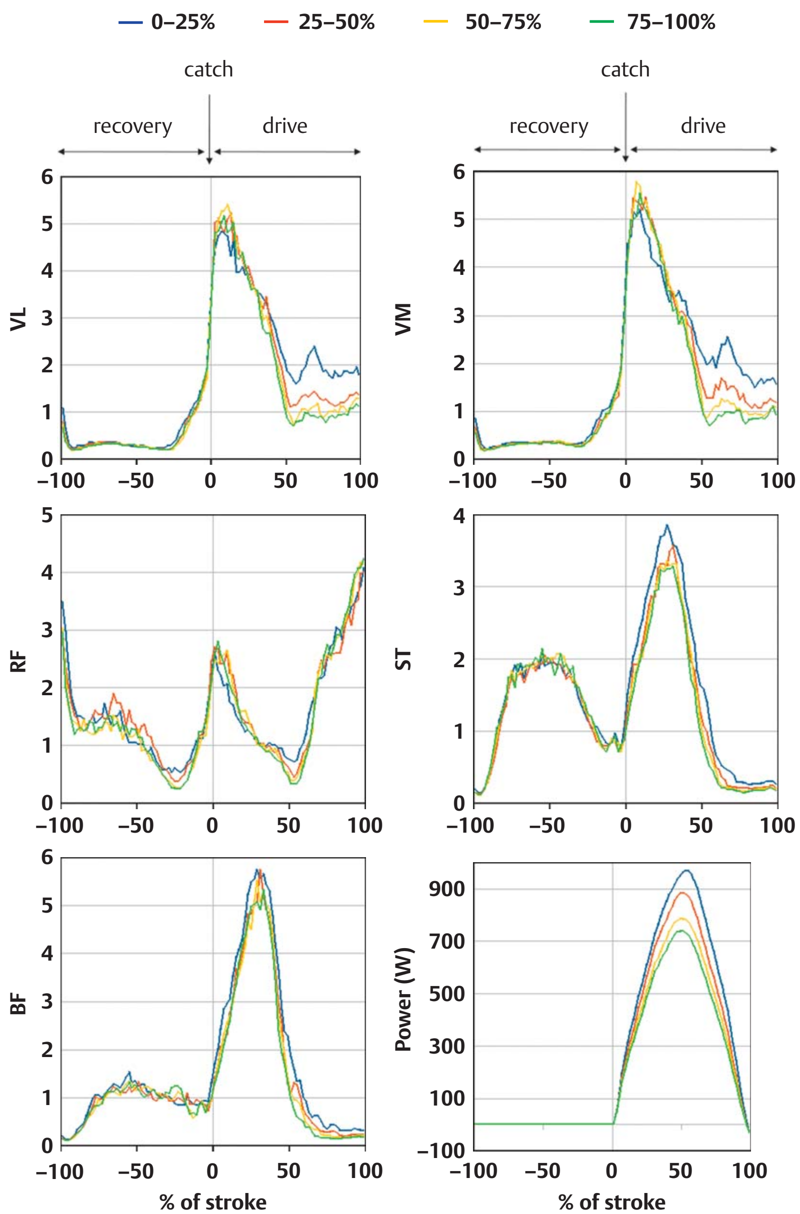

Fig. 5 Changes in electromyographic patterns, averaged across subjects, normalized with the mean EMG activity for the B1 and power during the all-out 500 m, and expressed in percentage of the recovery and drive phases of the stroke. VL: *vastus lateralis*, VM: *vastus medialis*, RF: *rectus femoris*, ST: *semitendinosus*, BF: *biceps femoris*.

Comparison of training sections

Although the stroke rates were in accordance with the orders (i.e., B1: 16–18 strokes.min^{-1}; B2: 18–20 strokes.min^{-1}), the mechanical parameters were not significantly changed between the training sections B1 and B2 (**Table 1**). Considering these 2 training sections, the muscle activity levels and the EMG patterns of the quadriceps and hamstring muscles did not change during the leg drive phase or the whole cycle (**Fig. 3**). One would expect that the changes in cadence were not sufficient to induce changes in muscle activity or that they induce changes in the EMG activity in non-recorded muscles (e.g., upper limb muscles, gastrocnemii). These 2 training sections did not induce different muscular solicitations regarding the muscles investigated. Due to increasing stroke rate, it is possible that the cardiorespiratory specific demands may slightly differ.
The start section was composed of 15 maximal rowing strokes which were similar to the starting period of a rowing race [8]. The mean power reached 592 W during the start section. This value is close to the values of 600–700 W reported on rowing ergometer during the start phase of a 2 000 m race [29, 30]. The stroke rate, the power and the mean torque experienced a two-fold increase between this start section and the 2 other sections (B1 and B2). The EMG activity levels of VL, VM, RF and ST muscles increased similarly relative to the power, while the EMG activity of BF muscle increased more moderately (**Table 2**). However, muscle activation patterns were changed with the power intensity (**Fig. 3**). During the start section, the VL and VM had an anticipated activity (first burst; **Fig. 3**) that began at the catch and continued throughout the leg drive. After this first burst of activity we reported a second activation burst after the leg drive between 50–100 % of stroke (**Fig. 3**) as shown by Janshen et al. [14]. However, our results highlight that this burst did not appear during the 2 less intensive training sections (**Fig. 3**). Interestingly, this second burst appeared only in 5 of

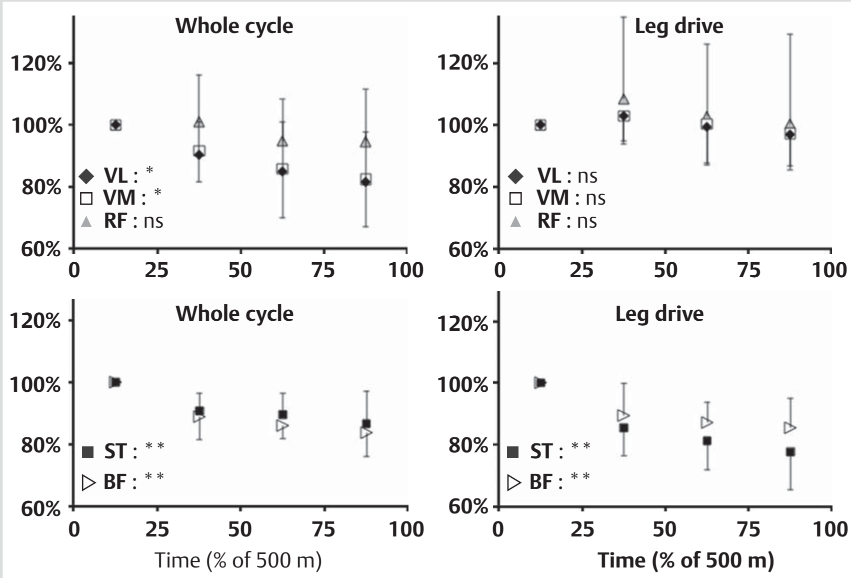

Fig. 6 Changes in electromyographic activity levels expressed in % of initial values during the all-out 500 m. VL: *vastus lateralis*, VM: *vastus medialis*, RF: *rectus femoris*, ST: *semitendinosus*, BF: *biceps femoris*. ns: non significant main effect of time ($p > 0.05$), *, **, ***: significant main effect and significant difference ($p < 0.05$, $p < 0.01$, $p < 0.001$, respectively) between the first quarter and the 3 other quarters.

the 9 subjects, indicating an important interindividual variability of this event. During this second burst, VL and VM muscles were in isometric contraction to stabilize the knee. The high level of muscular strength transmitted through the feet may explain this second activation burst. Janshen et al. [14] suggest that this second burst of the VL and VM activity provides a smooth transition from the drive phase into the recovery phase. In both the B1 and B2 sections the *rectus femoris* also had an activity burst that began at 50 % of the drive phase and decreased during the beginning of the recovery phase. The EMG patterns of this muscle also changed during the start section. During the whole stroke, RF muscle activity increased, however, a burst appeared at the catch that may assist the other quadriceps muscles to produce a high level of power.
As demonstrated by Rodriguez et al. [25] and Wilson et al. [31], the hamstring muscles had a delayed activity during the leg drive relative to the quadriceps muscles. This delay could be explained by the hamstrings' role as hip extensors. The major contribution of the hamstring muscles was localized throughout the leg drive while the leg extension and the hip extension occurred at the end of this phase [23]. For both hamstring muscles, the increase in stroke rate and power was associated with an activity burst during the recovery phase while the delay of the recovery phase was reduced. This stroke increase was associated with the decrease of the time to the recovery phase and could explain the activity burst of the leg flexors.

Maximal exercise over 500 m

The EMG activity of VL and VM decreased during the whole stroke, while it was not significantly changed during the leg drive. This discrepancy could be explained by a decrease in the activity during the second burst (50–100 % of the drive phase, ▶ **Fig. 5**). During this second burst VL and VM muscles mainly contract in isometric condition and do not contribute directly to the power production (see previous paragraph). However, the action of propulsion continues, including trunk extension and the upper limb action [18, 25, 31]. The decrease in muscular activity of the VL and VM induced a change in the stabilizing knee function and an increase of the relative recovery time for these muscles. This behaviour may delay muscular fatigue in these muscles which would allow maintenance of the muscular strength produced during the rowing stroke.
Therefore, the decrease in mechanical parameters during the 500 m (e.g., decrease in power of about 22 %), was not associated with changes in EMG activity of VL, VM and RF muscles during the leg drive (associated with the knee extension), while the activity of ST and BF decreased. 3 main hypotheses may explain these findings. (i) Muscular fatigue appeared in the quadriceps muscles. Despite the stable EMG activities, the muscular fatigue effect decreased the muscular capacity to produce force and could explain the decrease in power. (ii) The decrease in the muscular activity in ST and BF muscles may partially explain the decrease in power when we consider their functional role of synergist in the knee extension (paradoxical behaviour) with their action in the hip extension [7, 20, 33]. (iii) The decrease in power output during this maximal exercise could be associated with compensatory change in the activity of other non-recorded muscles such as *vastus intermedius*, and *gluteus maximus* low back or arm muscles.

Conclusion
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This study underlines the influence of exercise intensity on muscular activation patterns of the quadriceps and hamstring muscles. The findings indicated that the training sections B1 and B2 were similar. However, both sections showed less muscle activity level than the start section and the maximal exercise over 500 m. The study underlines the high level of contraction of the mono-articular quadriceps muscles (60–73 %MVC) for the start section when compared to the contraction during the B1 and B2 sections (42–51 %MVC). The VL and VM muscles behave as major contributors to the power output. These results provide an argument for coaches to submit their rowers to endurance force training and power muscular training for these muscles.

Acknowledgements

The present study was supported by the grants of the "Région des Pays de la Loire" (project OPERF2A). The authors are grateful to Kevin Fanien for his contribution, Bruno Boucher and the "Pôle France d'Aviron" for its technical support, and Ashleigh Kennedy for editing the manuscript.

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