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Effects of Prior Exercise on Force-Velocity Test Performance and Quadriceps EMG

Training & Testing

Abstract

This study investigated the effects of prior exercise on performance during a subsequent force-velocity (FV) exercise test. After determination of the individual maximal aerobic power (MAP) during maximal graded exercise testing, fifteen trained male subjects (age: 25 ± 3 y) were randomly assigned to perform the FV exercise test without prior exercise (NPE) or preceded by prior exercise (PE) (10 min at 60% of MAP, followed after 1-min rest interval by four intervals of 30-s cycling at 100% MAP with 15-s rest intervals, then 10 min recovery). Blood samples were drawn at rest, and then for each work load at the 3rd minute of recovery. Skin temperature (T_{sk}) from the rectus femoris and heart rate (HR) were measured continuously during prior exercise, the FV test, and during the 5-min recovery period at the end of each FV test. The Root Mean Square (RMS) of the surface electromyogram (EMG) signals obtained from the vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) were calculated during each sprint for each FV test. The lactate increase for each load (ΔLa) during the FV test was significantly less following PE than NPE. However, the lactate concentration (La) was significantly higher in the FV test following PE than NPE. There was an improvement in power output during the first two sprints (2 and 4 kg) following PE compared to NPE. There was also a more pronounced decrease in VL, VM, and RF RMS in PE compared to NPE. Our results showed that the first few sprints may provide sufficient prior exercise for the FV test. The higher lactate concentration following PE than NPE, despite no difference in maximum power, suggests that a large lactate accumulation may not be detrimental to FV test performance. However, a greater lactate concentration and T_{sk} may be associated with a decrease in RMS.

Key words

Force velocity · warm-up · blood lactate · power output · EMG

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Introduction

Numerous protocols have been used to assess anaerobic fitness, i.e., the capacity to perform intense muscular exercise. Some of these have used the force velocity (FV) test [12,18,29], which generally consists of repetitions of maximal 6-s sprints against increasing loads separated by 5-min recovery. During this test, some authors [1,12] have suggested that the first two sprints (against the two lower loads) provide sufficient prior exercise and familiarization with the test. However, to our knowledge no study has investigated the influence of specific prior exercise on the FV test.

Prior exercise, before intense exercise, is a well-accepted practice among athletes. Recently, Bishop [5] and Robergs [24] have shown that intermittent, high-intensity prior exercise improves performance at the onset (~ 30 s) of 2 min of intense exercise. They suggested that the increase in muscle temperature and oxy-

gen consumption following prior exercise may be responsible for the improved performance. Recently, active warm-up has also been reported to reduce blood and muscle lactate accumulation during intense dynamic exercise [13]. These results suggest that an intermittent, high-intensity prior exercise is likely to be beneficial for the performance of short-term-maximal efforts (< 10 s). However, the influence of this specific prior exercise on the performance of brief intense and repeated supramaximal 6-s sprints with an increasing load, such as occurs during the FV test, has not been investigated.

During the FV test, previous studies [12,18] have reported the rapid activation of glycolytic metabolism as, even following the first sprint, there is a significant increase in blood lactate accumulation. These authors have also observed a decrease in power after the attainment of peak power, concomitant with a plateau in blood lactate accumulation. Furthermore, despite the lack of correlation between the peak power and blood lactate accumulation, Mercier et al. [18] have suggested lactate accumulation to be a limiting factor of mechanical power during the FV test. Thus, prior exercise that results in a large accumulation of lactate may be detrimental to FV test performance.

It is known that a high lactate accumulation in muscles is associated with a decrease of muscular pH which perturbs the muscular contractile properties and induces a decrease in the contraction speed [17] and in the enzymatic activity of lactate dehydrogenase [2,3]. However, in addition to lactate accumulation, changes in the electrical activity of the recruited muscles may also explain the limitation of performance during the leg FV test. To our knowledge, no author has analysed leg muscles activities by surface electromyogram (SEMG) signals to explain this phenomenon. Thus, the aim of the present study was to investigate the effects of a prior exercise on subsequent performance and quadriceps muscle activity during the FV test.

Methods

Subjects

Fifteen trained males (age: 25 ± 3 y; stature 1.81 ± 0.03 m; mass: 77 ± 7 kg) took part in this study. Each subject was informed of the aim, procedures, possible risks, and potential benefits of the study before giving a written consent to participate in the project. The experimental procedures accorded with the ethical standards of the Helsinki Declaration of 1975.

Experimental protocol

Measurements were taken over two weeks for each subject. All tests were performed in a laboratory at $20\,°C$ between 15 – 18 p.m. Evaluations were conducted at the same time of day and separated by 72 h. During the first week, each subject performed a maximal graded exercise test on cycle ergometer for determination of his maximal aerobic power (MAP). Subjects were then familiarised with the cycle ergometer for the force-velocity test (FV test). In the second week and in random, counterbalanced order, each subject performed a FV test with prior exercise (PE) or a FV test without prior exercise (NPE). The subjects were recommended to refrain from heavy physical exercise three days before and between the sessions. They were also required to refrain

from taking coffee during the experimentation period, since caffeine has been shown to increase the peak power and blood lactate accumulation during the FV test [1].

Maximal graded exercise testing

Maximal oxygen consumption ($\dot{V}O_{2max}$), maximal aerobic power (MAP), and maximal heart rate (HR_{max}) were determined during the maximal graded exercise on a cycle ergometer (Monark 824-Crescent, AB, Varberg, Sweden) with the subject in a sitting position. After two minutes of recording resting physiological values, cycling started at 50 W and power output was subsequently increased by 25 W every two minutes. The pedalling speed was fixed at $60\,rev·min^{-1}$ during the entire test. To ensure that maximal oxygen uptake ($\dot{V}O_{2max}$) was reached, the following criteria had to be met:

a) stability of $\dot{V}O_2$ in spite of the increase in exercise intensity,
b) attainment of age-predicted maximal heart rate,
c) respiratory exchange ratio larger than 1.10, and
d) unable to maintain the pedalling frequency at $60\,rev·min^{-1}$, in spite of verbal encouragement.

Oxygen uptake was determined using an open circuit technique with the CPX system (Medical Graphics Corporation, St. Paul, MN, USA). Heart rate (HR) and skin temperature (T_{sk}) were continuously checked with an electrocardiogram (ECG) and a thermometer TH-5 (Physitemp Instruments, Inc. Service Departmental, Clifton, NJ, USA). This test was used to determine the MAP and to set the prior exercise intensity for each subject.

Force-velocity test

Three days after maximal graded exercise testing, each subject was requested to report to the laboratory for the force-velocity test with prior exercise (PE) or the force-velocity test without prior exercise (NPE). Both tests were conducted on a Monark 824. The FV test consisted of performing a maximal sprint against an increasing load. The duration of each sprint was fixed at 6 s, the maximal time for a subject to attain his maximal velocity after the starting signal. All subjects started the test against a load of 2 kg and then recovered for 5 min before repeating the same exercise against a load increased by 2 kg. When the pedalling rate was under $130\,rev·min^{-1}$, load was increased only by 1 kg to obtain a peak power output as precisely as possible. It was assumed that the subject attained the load (F_{Pmax}) corresponding to his maximal power if an additional increase in load (F_{Pmax} + 1 kg) induced a power decrease. As previously described [18], an automatic system was used to determine the maximal velocity (V) for each load and to calculate the force-velocity relations. The accuracy of the pedalling revolution was 3.3 ms. Power output was calculated as the product of load and velocity ($F \times V$). During the PE condition subjects completed a prior exercise based on the protocol employed by Robergs [24].

Prior exercise

The subjects rested on the Monark 824 for two minutes while expired air samples were taken. They then cycled at 60% of MAP at their predetermined cadence during the maximal graded exercise testing for 10 min. A 1-min rest interval was followed by four intervals of 30-s cycling at 100% MAP with 15-s rest intervals. Subjects then recovered for 10 min before the start of the force-velocity test.

Heart rate

A HR monitor (Polar Accurex Plus, Polar electro, Kemple, Finland) was used to monitor and store HR. During prior exercise, HR was collected continuously and the values at rest (R_0), at the end of prior exercise (maximal value: ePE), and then after the 10-min recovery period before the force-velocity test (oFV) were determined. During both force-velocity tests, HR was also recorded continuously and the values at rest, at the end of each sprint (maximal value), and after 5 min (R_5) at the end of both FV tests were determined.

Skin temperature

The skin temperature (T_{sk}) was measured using a thermometer TH-5. The probe was applied to the rectus femoris muscle. T_{sk} was collected continuously during prior exercise. The values at rest (R_0), at the end of prior exercise (maximal value: ePE), and after the 10-min recovery period before the force-velocity test (oFV) were determined. During both FV tests, T_{sk} was also recorded continuously. The values at rest, at the end of each sprint (maximal value), and after 5 (R_5) minutes at the end of both FV tests were determined. Then, temperature increase (∆ temperature) during the FV exercise test was calculated. ∆ temperature is the difference between the temperature of one sprint and the preceding sprint.

Blood lactate analysis

Blood samples were taken at rest (R_0), at the end of prior exercise (ePE), just before the first sprint of the FV test with prior exercise (oFV), three minutes after each repeated bout during the force-velocity test at 2, 4, 6 kg, F_{Pmax}, and $F_{Pmax} + 1$ kg, and five minutes after the end of the last bout. Micro punctures were made in the fingertips and 20 µL were collected using micro capillary tubes. For each subject, blood lactate was analyzed at the end of the FV test according to the principle of Miniphotometer Plus LP 20 (Monitor-8, Anglet, France). Then, blood lactate increase (∆ blood lactate) during the FV exercise test was calculated. ∆ blood lactate is the difference between blood lactate concentration of one sprint and the preceding sprint.

SEMG measurement

During PE and NPE tests, the surface electromyogram (SEMG) activities were recorded from the vastus medialis (VM), rectus femoris (RF), and vastus lateralis (VL) muscles of the right leg. Bipolar (20 mm inter-electrode distance) surface EMG recording (silver-silver chloride electrodes type Beckman with 8 mm active diameter, Sensormedics, Marnes la Vallée, France) was used. Before application of the electrodes, the skin was thoroughly cleaned by abrasion and sponging with an alcohol-ether mixture to reduce the interelectrodes impedance to below $1 – 3$ kΩ. RF electrodes were placed midway along the line connecting the anterior-superior-iliac-spine (ASIS) to the superior aspect of the patella. The electrodes were located over the VM at a position approximately 20% of the distance along a line connecting the medial gap of the knee to the ASIS. For the VL, electrodes were located one quarter of the distance proximal to the lateral tibial condyle on a line connecting this and the ASIS. To ensure the same electrode positions for both force-velocity tests, marks were made using indelible ink. During each sprint (6 s), the EMG activity of RF, VL, and VM occurred mainly during the extension of the leg. Thus the signal was periodic, as a silent period (flexion) followed a burst of activity (extension). After differential amplification (bandwidth ranging from 5 Hz to 2 kHz), the signal was conditioned and stored on magnetic tape (TEAC R-71). The EMG signals were then analysed using acquisition and spectrum analyser software (Spatol, Divergent, Compiègne, France) and a data computing software (Calvise, Divergent, Compiègne, France). Spatol software was equivalent to a real time spectrum analyser and was able to analyse periodic EMG activity such as bursts of RF, VL, and VM activity during supramaximal cycle ergometer. The EMG signals were sampled at 1024 Hz. Spatol software computed a mean power spectrum density (PSD) by calculating the Root Mean Square (RMS) value of eight consecutive spectra obtained from 0.5-s time windows. The mean PSD was defined by 256 points in amplitude and phase in the $0 – 512$ Hz Bandwidth. From SEMG signals, RMS data were calculated for each sprint, for each muscle, for each subject, and for all subjects. The RMS of quadriceps (Quad) was calculated as the sum of the RMS of RF, VL, and VM at each sprint. Then, RMS values VL, VM, RF, and Quad were expressed as percentages of values measured at the first sprint (2 kg) which was considered as 100% for each subject during PE and NPE.

Statistical analysis

For heart rate, skin temperature, blood lactate accumulation, and RMS, two-factor repeated measures analysis of variance (ANOVA) (Statview software, Institute SAS) were used to test for main effects. Significant main effects were followed by multiple paired t-tests (with Bonferroni correction) when the normality distribution (Kolmogorov-Smirnov test) and the equality of variance were verified. When these conditions were not obtained, a Wilcoxon's rank sum test was used. Differences were considered significant at $p < 0.05$.

Results

Maximal graded exercise testing

At the end of maximal graded exercise testing, the MAP was 296 ± 21 W and $\dot{V}O_{2max}$, HR_{max}, and the respiratory exchange ratio were: 54.8 ± 2.9 mL·kg^{-1}·min^{-1}, 179 ± 6 beats·min^{-1}, and 1.14, respectively.

Heart rate

There was no significant difference in resting heart rate (HR) between conditions (PE = 76 ± 8 vs. NPE = 75 ± 6 beats·min^{-1}, $p > 0.05$). At the end of prior exercise, HR was 175 ± 11 beats·min^{-1}. Just before the first sprint (2 kg), HR was significantly higher in PE than NPE (PE = 113 ± 7 and NPE = 76 ± 8 beats·min^{-1}, $p < 0.001$). During the FV test, HR remained higher for PE compared to NPE at 2 kg (149 ± 9 vs. 132 ± 6 beats·min^{-1}, $p < 0.001$), 4 kg (151 ± 11 vs. 140 ± 6 beats·min^{-1}, $p < 0.01$), and at 6 kg (154 ± 10 vs. 144 ± 5 beats·min^{-1}, $p < 0.05$). For the highest loads (F_{Pmax} and $F_{Pmax} + 1$) and during the recovery period, no significant difference was observed between the two conditions (Table **1**).

Skin temperature

There was no significant difference in skin temperature between the two conditions at rest (R_0), (PE = 31.2 ± 0.7 °C vs. NPE = 31.1 ± 0.6 °C, $p > 0.05$). Skin temperature was 32.2 ± 0.8 °C at the

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Table 1 Significantly different from NPE

| | Heart rate (beats·min⁻¹) | | Temperature (°C) | | Blood lactate accumulation (mmol·L⁻¹) | |
	PE	*NPE*	*PE*	*NPE*	*PE*	*NPE*
R_o	76 ± 8	75 ± 6	31.2 ± 0.7	31.1 ± 0.6	1.6 ± 0.6	1.7 ± 0.1
ePE	175 ± 11	–	32.2 ± 0.8	–	11.5 ± 1.2	–
oFV	113 ± 7***	76 ± 8	33.2 ± 0.7***	31.1 ± 0.6	10.8 ± 1.1***	1.7 ± 0.1
2 kg	149 ± 9***	132 ± 6	32.9 ± 0.5*	32.2 ± 0.6	11.0 ± 1.1***	3.6 ± 0.6
4 kg	151 ± 11**	140 ± 6	33.2 ± 0.7	32.6 ± 0.5	11.3 ± 1.5**	5.8 ± 1.0
6 kg	154 ± 10*	144 ± 5	33.5 ± 0.8	33.1 ± 0.7	11.6 ± 1.4**	7.9 ± 0.9
F_{Pmax}	153 ± 11	147 ± 6	33.7 ± 0.7	33.4 ± 0.4	11.9 ± 1.5**	9.2 ± 0.8
F_{Pmax} + 1 kg	152 ± 10	148 ± 7	34.1 ± 0.6*	33.7 ± 0.5	12.1 ± 1.6*	9.6 ± 0.7
R_5	101 ± 5	102 ± 7	34.1 ± 0.7*	33.6 ± 0.5	11.5 ± 1.8*	9.1 ± 1.6

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

end of prior exercise. Just before the first sprint (2 kg), skin temperature was significantly higher in PE compared to NPE (PE = 33.2 ± 0.7 °C and NPE = 31.1 ± 0.6 °C, $p < 0.001$). During the FV test, skin temperature remained higher in PE than in NPE at 2 kg (32.9 ± 0.5 °C vs. 32.2 ± 0.6 °C), F_{Pmax} + 1 kg (34.1 ± 0.6 °C vs. 33.7 ± 0.5 °C), and after the 5-min (R_5) recovery period (34.1 ± 0.7 °C vs 33.6 ± 0.5 °C) (Table **1**). Skin temperature increase (∆ temperature) during the FV exercise test (Fig. **4A**) was significantly greater during NPE than during PE from 2 kg to 6 kg, with no significant difference at F_{Pmax} or F_{Pmax+1}.

Blood lactate concentration
At rest (R_0), blood lactate concentration was similar between the NPE and the PE (1.7 ± 0.1 vs. 1.6 ± 0.6 mmol·L⁻¹). The blood lactate concentration was 11.5 ± 1.2 mmol·L⁻¹ at the end of prior exercise. Just before the first sprint, blood lactate concentration was significantly higher in PE than NPE (10.8 ± 1.1 vs. 1.7 ± 0.1 mmol·L⁻¹, $p < 0.001$). Blood lactate concentration remained higher throughout PE compared to NPE with significant differences after all loads and after 5 min of recovery (R_5) (Table **1**). Blood lactate increase (∆ Blood lactate) during the FV exercise test (Fig. **4B**) was significantly higher during NPE than in PE from the load equal 2 kg to the load corresponding to the maximal anaerobic power output (F_{Pmax}), with no significant difference observed at F_{Pmax+1}.

Power output
Group results for power output and peak power recorded during NPE and PE tests are summarized in Fig. **1**. Average power output was higher in PE compared to NPE at 2 kg (PE = 377 ± 10 and NPE = 350 ± 29 W, $p < 0.01$) and at 4 kg (PE = 689 ± 29 and NPE = 657 ± 36 W, $p < 0.05$). No difference was observed between the maximal power output in the two conditions (NPE = 992 ± 104 and PE = 965 ± 95 W, p = 0.5).

RMS profiles
During the FV test, a significant difference between NPE and PE was found in the RMS of VL at 2, 4, 6 kg, and F_{Pmax}. However, no difference was found between both conditions for the RMS of VL at F_{Pmax} + 1 kg. For VM, the significant difference between NPE and PE was obtained only at the first load (2 kg). However, there
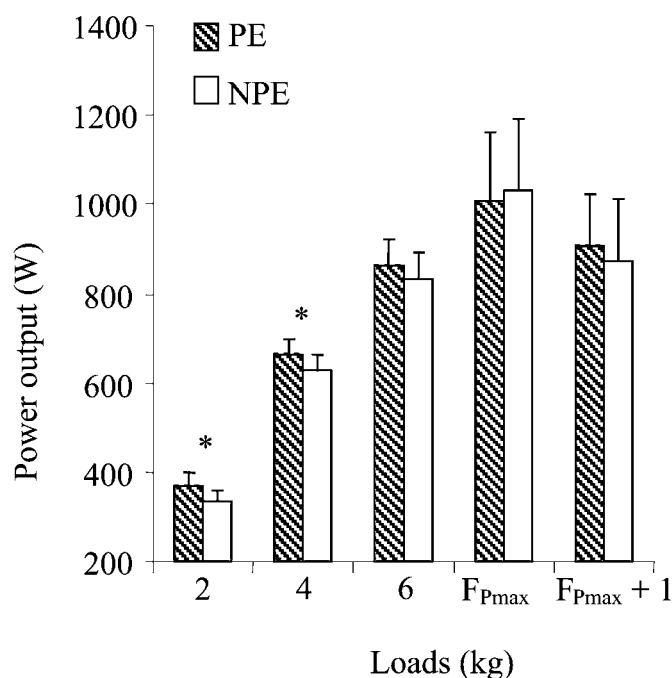

Fig. 1 Mechanical power output (W) during PE and NPE tests at the three common loads for all subjects (2, 4, 6 kg), the load corresponding to peak mechanical power (F_{Pmax}), and the following load (F_{Pmax} + 1 kg) (* significantly different from NPE; $p < 0.05$ and ** p significantly different from NPE; $p < 0.01$).

was significant difference between NPE and PE concerning the RMS of RF and Quad at all loads with the higher value in NPE (Fig. **2**). But, when the RMS values were expressed relative to that achieved on the first sprint (2 kg), the RMS percent (%) for each muscle increased more in PE than in NPE (Fig. **3**).

Discussion

The main result of this study is the significant improvement in power output during the first two sprints (2 and 4 kg), without a significant change in maximal mechanical power output during the force-velocity test following high-intensity, intermittent prior exercise. In addition, prior exercise was associated with a
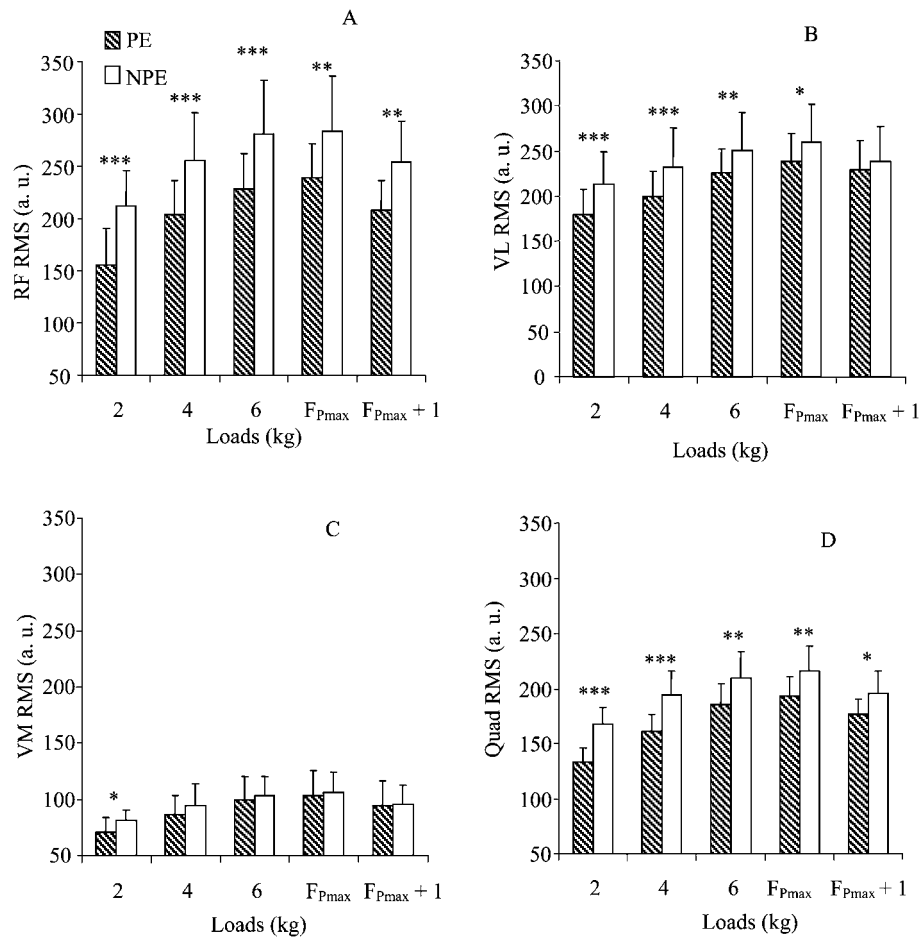
Fig. **2 A** to **D** Absolute values of RMS of the vastus lateralis (VL), rectus femoris (RF), vastus medialis (VM), and quadriceps (Quad) during PE and NPE. For other definitions see Fig. **1** (* p < 0.05, ** p < 0.01, and *** p < 0.001). * significantly different from NPE.
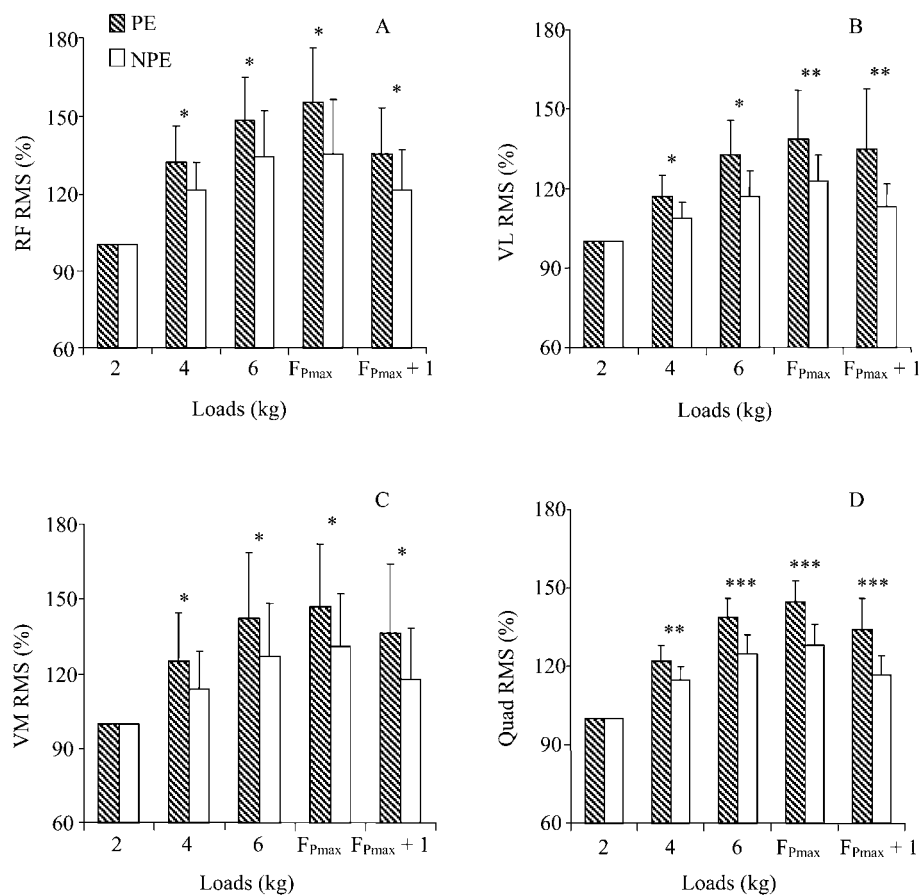

Fig. **3 A** to **D** RMS of the vastus lateralis (VL), rectus femoris (RF), vastus medialis (VM), and quadriceps (Quad) values expressed as percentages of values measured at the first sprint (2 kg) which was considered as 100% for each subject during PE and NPE. For other definitions see Fig. **1** (* p < 0.05, ** p < 0.01, and *** p < 0.001). * significantly different from NPE.
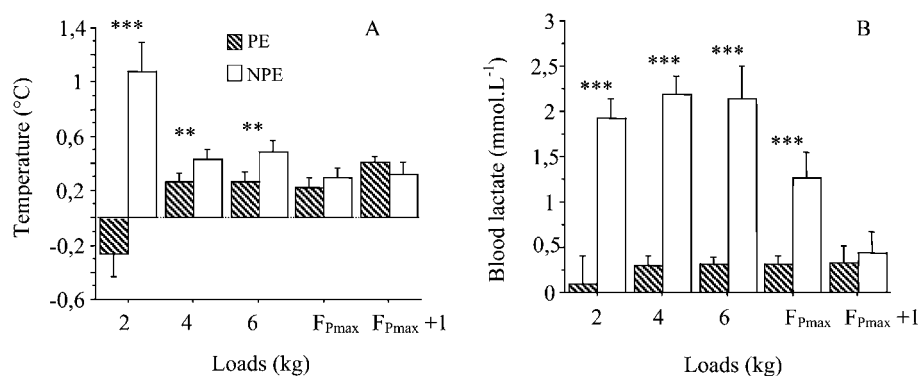
Fig. **4 A** and **B** Evolution of temperature (**A**) and blood lactate increase (**B**) for each load during the FV exercise test. Δ Blood lactate is the difference between blood lactate concentration of one sprint and the preceding sprint and Δ Temperature is the difference between temperature of one sprint and the preceding sprint (for other definitions see Fig. **1** [** p < 0.01 and *** p < 0.001]). ** significantly different from NPE.

lower RMS for the superficial quadriceps muscles (VL, VM, and RF) at all loads during the force-velocity test.

We hypothesized that prior exercise would increase power output during the force-velocity test. Generally, prior exercise is proposed to improve high-intensity performance via a number of temperature-related effects and/or by serving as a preparatory stimulus for the systems involved in oxygen transport and utilization, thereby allowing an individual to reach a high level of aerobic metabolism more rapidly [5,24]. In support of the latter, prior exercise has previously been reported to increase the availability of precursors for oxidative metabolism [13]. A faster aerobic contribution after prior exercise has also been proposed to result from enhanced oxygen delivery associated with increased muscle blood flow [11,16], and facilitation of oxyhaemoglobin dissociation [6]. However, the common hypothesis that greater oxygen delivery will improve $\dot{V}O_2$ kinetics is not supported by the research demonstrating that limitations in oxygen utilization during the initial phase of dynamic exercise are not caused by insufficient oxygen availability [2]. Thus, in the present study, the improvement in performance of the first two sprints following PE (Fig. **1**) could be the result of increased muscle temperature and/or aerobic metabolism (as indicated by the increased skin temperature and heart rate) (Table **1**).

Power output produced during the FV test is the product of the braking force and velocity. As both FV tests were performed by the same subjects on the same ergocycle, morphological and mechanical factors, such as leg length and crank length, cannot explain the improvement of cycling velocity during the PE trial [15]. Furthermore, as the loads at the first two frictions (2 and 4 kg) were constant, the improvement of power output depends on the improvement of cycling velocity during the PE test. Thus, one of the effects of prior exercise was to increase the cycling velocity obtained at 2 and 4 kg during the FV test. This result is in line with the results of Sargeant [26] which showed that the effect of warming the muscle was to increase the power output by 10% per °C at the highest speed and only by 2% per °C at the slowest pedalling speed. As pedal speeds in the present study were greatest at the lowest loads, this may also have contributed to why significant improvements in power output were only seen at the lowest loads. Despite improvements in power output during the first two loads (2 and 4 kg), the maximal power output (Fig. **1**) was not significantly different at the corresponding friction load (F_{Pmax}) during both FV tests. Thus, despite significant changes in the metabolic responses (e.g., blood lactate accu-

mulation), it appears that prior exercise does not increase F_{Pmax} during the FV test. A possible explanation for no significant change in maximal power output is that during the FV test the first few loads provide a sufficient prior exercise effect. This is supported by the non significant difference in HR and T_{sk} between the two conditions after the first two loads (Table **1**). This suggests that PE is not necessary to determine F_{Pmax} during the FV test, perhaps because of the very short duration of the adopted exercise. Furthermore, these results also suggest that the improved power output of the first 2 workloads can largely be attributed to an increase in temperature.

Despite incorporating a similar prior exercise protocol, the blood lactate concentration just before the PE test (10.8 ± 1.1 mmol·L⁻¹) in the present study was higher than that of Robergs [19] (5.2 ± 0.8 mmol·L⁻¹). This difference may be due to differences in the blood lactate analysis method and/or the subjects' fitness status (recreationally active males versus trained males). In the present study, blood lactate concentration values (Table **1**) also did not differ significantly between the end of prior exercise and just before starting the FV test (11.5 ± 1.2 vs. 10.8 ± 1.1 mmol·L⁻¹, p > 0.5) despite the 10-min recovery. This result is comparable to that of Billat [4] and Robergs [24] who reported that blood lactate concentration remained unchanged despite a 10–15-min recovery separating the intermittent prior exercise from the subsequent intense exercise. This can most likely be explained by the passive nature of recovery [10].

In this study, the blood lactate concentration remained higher in the PE condition compared to the NPE condition at the end of the FV test. This is in contrast to previous studies that have reported a similar post-exercise blood lactate concentration following prior exercise or no prior exercise [4,5,24]. This may be due to the higher blood lactate concentration obtained during the prior exercise in the present study and/or the nature of the FV test which consists of repeated, supra maximal, 6-s sprints separated by 5-min recovery against increasing loads. In contrast, previous research [4,5,24] investigated the effects of prior exercise on blood lactate concentration following intense continuous exercise. Despite the higher blood lactate concentration in PE than in NPE, there was no difference in peak power output for either FV test. This is consistent with the results of previous research which suggests that lactate doesn't necessarily cause fatigue [19]. The differences between pre (onset of FV test) and post (end of FV test) values of blood lactate concentration in PE (1.3 ± 0.5 mmol·L⁻¹) and NPE (7.9 ± 0.6 mmol·L⁻¹) showed the

significant increase in blood lactate during NPE compared to PE. Our results are consistent with those of previous studies [4, 5, 24] which also showed a smaller change in blood lactate concentration during an intense exercise preceded by an intermittent intense warm-up compared to an intense exercise preceded by low or no warm-up. These authors attributed the smaller change in blood lactate concentration following prior exercise to the probable glycogen depletion in fast-twitch fibres during the intense warm-up [11, 23].

Surface electromyography (EMG) signals have been extensively used to non-invasively characterise the electrophysiological fatigue process during dynamic contractions [7, 8, 20]. Expression of the EMG signals in the time domain (i.e., amplitude) allows for evaluation of neuromuscular activation patterns, since it is believed to reflect motor-unit activation [28]. Moreover, it may be at least partially related to the efferent neural output to the muscle [9, 22].

In this study, absolute RMS increased from the first sprint until the sprint corresponding to the maximal mechanical power output (F_{Pmax}) and then decreased during the load corresponding to the maximal mechanical power plus 1 kg ($F_{Pmax} + 1$ kg). This result may be related to the increase in power output possibly as a result of the recruitment of additional motor units (MU) [12]. In the present study, the decrease of power at $F_{Pmax} + 1$ kg was concomitant with the RMS decrease in RF, VL, and VM. However, the present data do not allow us to determine if the decrease of the RMS RF, VL, and VM is a result of a decrease in the number of recruited MUs, a decrease in MU firing rate, or changes in characteristics of the MU action potential (e.g., amplitude, duration, or shape).

When we compared the RMS of the RF, VL, and VM in both FV tests (Fig. **2**), we observed a difference between PE and NPE with significantly lower RMS in PE. Several authors have noted that changes in the components of the myoelectrical activity during intense exercise are associated with muscle lactate accumulation [7, 14]. In the present study, the greater blood lactate concentration during PE may have been associated with the lower RMS during PE compared to NPE. In addition, the lower RMS of the RF, VL, and VM could be the consequence of the increase of skin temperature observed during PE. These results are in agreement with those of Stewart [27], Petrofsky [21], and Rutkove [25]. These authors showed a lower RMS following an increase in muscle temperature. In addition Winkel [30] showed an increase in amplitude of the RMS resulting from a decrease in muscle temperature. As many factors are known to affect the SEMG signal, we conducted both FV tests using the same electrodes and placement in order to minimize the effect of changing electrode and/or placement. Thus, the altered SEMG signals in this study are likely to have resulted from changes in skin temperature and blood lactate accumulation during the FV test. The lower value of both these variables in PE than in NPE may therefore have contributed to the lower RMS of the RF, VL, and VM during PE compared to NPE.

When we expressed the RF, VL, and VM RMS and their sum (Quad RMS) as percentages of values measured at the first sprint (2 kg), considered as 100% for each subject during both FV tests (Fig. **3**),

there was a greater relative increase in RF, VL, VM, and Quad RMS in PE than in NPE. Interestingly, the greater increase in relative RMS was associated with a smaller relative increase in both blood lactate concentration and skin temperature in PE compared to NPE (Fig. **4**). These results suggest that both absolute and relative values of RMS may be influenced by absolute and relative values of blood lactate accumulation and/or muscle temperature.

In summary, the results of the present study demonstrate that prior exercise is associated with a significant improvement in the first two sprints (2 and 4 kg) of the force velocity test, without a significant improvement in maximal mechanical power output. The absence of a significant improvement in maximal mechanical power output suggests that the first few sprints may provide sufficient prior exercise for this test. The improvement in performance of the first two sprints following prior exercise may be associated with a number of temperature-related mechanisms (as indicated by the increase in thigh skin temperature).

Acknowledgements

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