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**Effect of body tilt angle on fatigue and EMG activities in lower limbs during cycling**

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4 **ABSTRACT**  
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6 **Purpose:** This study compared the rate of fatigue and lower limb EMG activities during high-intensity  
7 constant-load cycling in upright and supine postures.  
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10 **Methods:** Eleven active males performed seven cycling exercise tests: one upright graded test, four fatigue  
11 tests (two upright, two supine) and two EMG tests (one upright, one supine). During the fatigue tests  
12 participants initially performed a 10s all-out effort followed by a constant-load test with 10s all-out bouts  
13 interspersed every minute. The load for the initial two fatigue tests was 80% of the peak power (PP)  
14 achieved during the graded test and these continued until failure. The remaining two fatigue tests were  
15 performed at 20% PP and were limited to the times achieved during the 80% PP tests. During the EMG  
16 tests subjects performed a 10s all-out effort followed by a constant-load test to failure at 80% PP.  
17 Normalised EMG activities (% maximum, NEMG) were assessed in 5 lower limb muscles.  
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20 **Results:** Maximum power and maximum EMG activity prior to each fatigue and EMG test were unaffected  
21 by posture. The rate of fatigue at 80% PP was significantly higher during supine compared with upright  
22 posture ( $-68 \pm 14$  vs.  $-26 \pm 6$  W.min<sup>-1</sup>, respectively,  $P < 0.05$ ) and the divergence of the fatigue responses  
23 occurred by the 2<sup>nd</sup> minute of exercise. NEMG responses were significantly higher in the supine posture by  
24 1-4 minutes of exercise.  
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27 **Conclusion:** Fatigue is significantly greater during supine compared with upright high-intensity cycling  
28 and this effect is accompanied by a reduced activation of musculature that is active during cycling.  
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32 **Key words:** posture, exercise, performance, muscle activity  
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## INTRODUCTION

In humans, the time sustained during maximal cycling is significantly longer during an upright compared with a supine posture (Egaña et al. 2007; Eiken 1988; Koga et al. 1999; Terkelsen et al. 1999). This effect is much larger for high-intensity (i.e. ~80% Peak Power, PP) constant-load exercise than for maximal graded exercise (~100 vs 15%) and it is independent of gender and/or aerobic capacity ( $\dot{V}O_{2max}$ ) (Egaña et al. 2006; Egaña et al. 2007). This postural effect on cycling performance is associated with a faster dynamic response of  $\dot{V}O_2$  during the early phase of exercise (Convertino et al. 1984; Egaña et al. 2006; Koga et al. 1999; Leyk et al. 1994) and a lower blood lactate response (Egaña et al. 2007; Leyk et al. 1994) in the upright compared with supine posture .

The rate of muscle fatigue (defined as the rate of decline in MVC, (Gandevia 2001)) is also influenced by raising or lowering the active muscles relative to the level of the heart in humans. Lowering the active muscles below the level of the heart decreases muscle fatigue during involuntary (i.e. electrically stimulated) exercise of the *adductor pollicis* muscle (Fitzpatrick et al. 1996) and during voluntary exercise of the *tibialis anterior* (Tachi et al. 2004) and *triceps surae* (Egaña and Green 2005, 2007) muscles; and decreases integrated EMG responses during voluntary exercise of the tibialis anterior (Tachi et al. 2004). This effect appears to be related to muscle blood flow, as the postural effect on fatigue is absent when blood flow is occluded (Egaña and Green 2005; Tachi et al. 2004), and abrupt changes in blood flow during exercise lead to equidirectional changes in muscle force production (Fitzpatrick et al. 1996; Hogan et al. 1994). This postural effect on muscle fatigue also depends on the exercise intensity and there is a critical intensity below which the effect is not observed (Egaña and Green 2007; Fitzpatrick et al. 1996).

To our knowledge the postural effect on fatigue during cycling (i.e. rate of decline in peak power output, (Beelen and Sargeant 1991)) has not yet been measured. In the present study, we aimed to quantify muscle fatigue responses during upright versus supine high-intensity constant-load cycling to test, and to shed light on the activation of lower limb muscles under these conditions, we also assessed electromyographic activities in several of the lower limb muscles. **Given that in isolated human limbs muscle fatigue and muscle activity are reduced when active muscles are lowered below the level of the heart compared to**

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4 **above the level of the heart (Egaña and Green 2005; Tachi et al. 2004) we hypothesized that fatigue**  
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6 **and lower limb muscle activation would be lower during upright compared with supine cycling.**  
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## 10 **METHODS**

### 11 *Subjects*

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14 All experimental procedures were carried out in accordance with the Declaration of Helsinki, and were  
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16 approved by the Trinity College Dublin Research Ethics Committee. Eleven active male university students  
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18 participated in the study (mean  $\pm$  SD; **age:** 20.7  $\pm$  1.0 yr; **height:** 178.9  $\pm$  3.5 cm; **weight:** 72.8  $\pm$  7.2 kg).  
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20 Each subject underwent a medical examination by a qualified physician prior to participation. Subjects with  
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22 any history of heart murmurs, chest pain, high blood pressure, shortness of breath, asthma, dizziness,  
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24 anaemia, fainting, joint pain, ringing in the ears or who had sustained a recent injury were excluded from  
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26 taking part in the study. On the day of the medical examination each subject was familiarised with the  
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28 experimental equipment and testing procedures and advised of any risks and benefits of participation in the  
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30 study. Each subject then provided written informed consent prior to testing.  
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### 33 *Exercise protocol overview*

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36 Each subject attended the laboratory on six occasions separated by at least 48 hours so as to complete seven  
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38 cycling exercise tests (**Table 1**). On day 1, a graded test to failure was performed in an upright posture. On  
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40 days 2 & 3, two fatigue tests were performed in a random order at 80% of the peak power achieved in the  
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42 graded test (80% PP), one in an upright posture and one in a supine posture. On day 4, two further fatigue  
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44 tests (upright and supine) were performed at 20% of the peak power achieved in the graded test (20% PP).  
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46 On this occasion each test was separated by 30 min rest. On days 5 and 6, two constant load tests (upright  
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48 and supine) were performed in a random order at 80% PP for the assessment of EMG activities (EMG  
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50 tests). Before each testing day subjects were asked to refrain from consuming caffeine and alcohol in the 24  
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52 hours prior to testing in addition to limiting exercise to activities of daily living. The body position used for  
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54 the upright and supine postures have been described previously (Egaña et al. 2006; Egaña et al. 2007).  
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56 Briefly, in both postures hip and knee angles were similar and the arms were held loosely at the sides so as  
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58 to minimise any involvement from the upper body associated with gripping of the handlebars. In the supine  
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4 posture a harness was worn to secure the subject to the ergometer and the ergometer was raised 20 cm off  
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6 the floor to allow a suitable foot clearance.  
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10 Exercise was performed on an electrically braked cycle ergometer (Lode Excalibur Sport, Groningen,  
11 Netherlands). For all fatigue tests the cycle ergometer was controlled via a connected PC running Lode  
12 Wingate software (v1.0.12, Groningen, Netherlands). The cycling cadence required for each test was 60  
13 rpm except for the fatigue tests where 10 s of all-out cycling was interspersed each minute. Failure in any  
14 exercise test was defined as an inability to maintain a minimum cadence of 50 rpm for 3 s. During exercise,  
15 heart rate (HR) was continuously monitored and recorded every 5 s using a HR monitor (Polar Electro,  
16 S725, Finland). In addition, during the graded and EMG tests (but not during the fatigue tests) subjects  
17 wore a facemask to continuously collect expired air using an online metabolic system (Metalyser, Cortex  
18 Biophysik, Germany) as has been previously described (Egaña et al 2007). Analysis of expired air allowed  
19 determination of O<sub>2</sub> uptake ( $\dot{V}O_2$ ), CO<sub>2</sub> production ( $\dot{V}CO_2$ ), minute ventilation ( $\dot{V}_E$ ), and the respiratory  
20 exchange ratio (RER) every 10 s during all rest and exercise periods. The power output at the ventilatory  
21 threshold (VT) was identified for each subject using the V-slope method (Beaver et al. 1986). Other  
22 measures specific to each test are described below.  
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### 39 *Graded test*

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41 Subjects initially performed a maximal graded test in the upright posture. **Following a resting period of 3**  
42 **min in the exercise position**, the exercise test began with 3 min cycling at 60W and increased  
43 incrementally by 30 W every 3 min until failure. Time to failure was recorded and the maximum workload  
44 achieved was defined as the highest workload sustained for at least 1 min. This was subsequently used to  
45 determine the 80% and 20% workloads to be used for the fatigue tests and constant load tests.  
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### 53 *Fatigue tests (80% and 20% PP)*

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55 Four fatigue tests were completed: two at each workload (80% and 20% PP) and each posture. Previously  
56 our investigations had predominantly focused on constant load cycling at 80% PP and as such, with the  
57 incorporation of a 10 s bout of all-out cycling each minute it was expected that this would impact on the  
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4 time to failure during the fatigue test. Therefore, so as to quantify the contribution of the repeated (each  
5 minute) 10 s efforts of all-out cycling alone on the time to failure at 80% PP, a fatigue test at a workload  
6 designed to induce minimum fatigue (i.e. 20% PP; mean power: ~50W) was performed in each posture.  
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12 To determine the maximal power achievable in each posture, and when comfortable in the exercising  
13 position, subjects completed a single peak effort test comprising 45 s cycling at 100 W followed by 10 s  
14 all-out cycling and then 3 min rest (i.e. no cycling). The fatigue test commenced with cycling at the  
15 specified workload for 45 s (80% or 20% PP) after which subjects completed 10 s of all-out cycling  
16 followed by 5 s of unloaded cycling. This sequence was subsequently repeated until failure during the 80%  
17 PP conditions but the exercise time for the fatigue tests at 20% PP was limited to that achieved during the  
18 same test at 80% PP. The peak power achieved during each bout of all-out cycling was recorded to enable  
19 an estimation of the rate of fatigue while cycling at a constant load (80% or 20% PP) in each posture. The  
20 decline in peak power during each all-out effort was described using a linear function ( $y = a + bx$ ), where  $y$   
21 is power,  $x$  is time, parameter  $a$  provides power at  $t=0$  (i.e. predicted peak power) and parameter  $b$   
22 represents the rate of fatigue.  
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### 34 35 36 *EMG tests (80% PP)*

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38 Two constant load tests at 80% PP were randomly performed in separated days (upright and supine).  
39 Initially subjects completed a single peak effort test comprising 45 s cycling at 100W followed by 10-s all-  
40 out cycling to measure muscle activation (see below) during maximal power production. Subjects then  
41 rested for 10 min after which they performed a constant load test at 80% PP until failure.  
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49 Electromyography: The right leg was prepared for surface electromyography (sEMG) recordings from five  
50 lower limb skeletal muscles (*vastus lateralis* (VL); *biceps femoris* (BF); *gastrocnemius medialis* (MG);  
51 *rectus femoris* (RF) and *gluteus maximus* (GMax)). The skin recording sites were selected from the belly of  
52 the muscle where possible and prepared by shaving, abrading and cleaning with alcohol (70%). Two  
53 bipolar Ag/AgCl recording electrodes were placed on the skin at the recording sites 25 mm apart (centre to  
54 centre) and in a plane estimated to be parallel to the direction of muscle shortening during contraction. A  
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4 reference electrode was attached to the anterior superior iliac crest. EMG signals were band-pass filtered  
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6 (10-500Hz) and sampled at 1000 Hz using a PowerLab connected to a PC running Chart recording software  
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8 (v5.0, ADInstruments, Australia). On completion of the first test electrode locations were carefully marked  
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10 with a permanent pen. The EMG (rms) values were calculated on a burst by burst basis. The criteria for the  
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12 onset and offset activation was based on a voltage threshold (3SDs above baseline). The average rms value  
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14 during the initial 30 seconds of unloaded exercise was subtracted from all rms measures during subsequent  
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16 exercise, and this latter value was normalized to the maximum rms (NEMG). The maximum rms was  
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18 determined by averaging three consecutive bursts when the maximum power output was achieved during  
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20 the 10 s all-out test **and it was highly reproducible: the mean coefficient of variation (including all**  
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22 **tested muscles) of the peak rms was (mean  $\pm$  SD)  $4.39 \pm 4.28$  in the upright posture and  $3.66 \pm 2.58$  in**  
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24 **the supine posture.** NEMG measurements during constant-load exercise were based on EMG activities  
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26 during five consecutive bursts (i.e. crank cycles) recorded at minute intervals. Technical difficulties  
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28 precluded the recording of muscle activities from the *gastrocnemius medialis* and *gluteus maximus* muscles  
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30 in two subjects and *biceps femoris* muscles in seven subjects.  
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### 34 *Statistical analyses*

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36 'Peak' responses during the EMG and fatigue 80%PP tests were compared using a paired *t*-test. Effects of  
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38 body posture and intensity on peak power, rate of fatigue and EMG activities were identified using a two-  
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40 way (**posture x intensity**) repeated-measured ANOVA. Differences were then located using Tukey's HSD  
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42 test. The level of significance was set at  $P < 0.05$ . Results are shown as mean  $\square$  SD.  
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## 46 **RESULTS**

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48 *Graded Test:* Exercise times and peak physiological responses for all subjects ( $n = 11$ ) during the graded  
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50 test are shown in **Table 2**. For all subjects the VT was at or below 80% of the maximum workload.  
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55 *Fatigue Tests (80% and 20% PP):* Mean cycling time during the 80% PP condition was significantly longer  
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57 ( $P < 0.05$ ) in the upright than the supine posture (**Table 3**). Figure 1 shows the individual fatigue responses  
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59 to the 4 conditions. The mean rate of fatigue for each condition is shown in Fig 2. Supine and upright  
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4 responses were significantly different at 80 % PP condition ( $-68 \pm 14$  vs.  $-26 \pm 6$  W.min<sup>-1</sup>, respectively,  $P <$   
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6 0.05) but not at 20% PP condition ( $20 \pm 12$  vs.  $-5 \pm 7$  W.min<sup>-1</sup>, respectively,  $P > 0.05$ ). In addition, there  
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8 was no significant fatigue in the 20% PP condition (i.e. the rate of fatigue did not differ significantly from  
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10 zero) in any of the postures.

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14 A comparison of the mean fatigue responses at 80% PP between supine and upright position is shown in  
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16 Fig 3. **Considering all eleven subjects there was a main effect of time ( $P < 0.01$ ) but not posture ( $P =$   
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18 **0.49**). However, there was a significant interaction between posture and time ( $P = 0.049$ ) and Tukey's  
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20 **HSD test showed that fatigue was only different in the supine posture at the second minute of**  
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22 **exercise.** Power outputs at failure were the equivalent of 71% (upright) and 68% (supine) of the maximum  
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24 power achieved prior to each test (i.e. at time = 0). These maximum power outputs (i.e. at time = 0) were  
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26 not different between the upright and supine postures during the 80% PP ( $654 \pm 168$  vs.  $595 \pm 195$  W,  
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28 respectively) or 20% PP ( $750 \pm 150$  vs.  $699 \pm 171$  W, respectively) fatigue tests.**

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32 *EMG Tests (80% PP):* Mean exercise times and peak physiological responses for all subjects in both  
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34 postures during the EMG cycling tests are shown in **Table 3**. Exercise times were significantly longer ( $P <$   
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36 0.05) in the upright compared with supine posture. In addition, exercise times for each posture were  
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38 significantly longer compared with the times obtained during the 80% PP fatigue tests. Peak values for  
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40  $\dot{V}O_2$ ,  $\dot{V}_E$  and HR were higher ( $P < 0.05$ ) but RER values lower in the upright compared with the supine  
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42 posture. Maximum RMS responses for all muscles obtained in both postures during the initial peak effort  
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44 test (i.e. time=0) are shown in Fig 4. There was no postural effect on maximum RMS for any of the five  
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46 muscles. NEMG responses (% maximum) are shown in Fig 5. Each mean value in the graphs shown in Fig  
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48 5 is based on responses of all subjects (i.e.  $n = 11$  for VL & RF;  $n = 9$  for MG & GMax and  $n = 4$  for BF)  
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50 so that the maximum exercise time for each NEMG response shown (prior to the 'failure' time-point) is  
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52 limited by the subject who failed first. NEMG responses were significantly higher in the supine compared  
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54 with upright posture at failure in all muscles. In addition, supine NEMG responses were also higher at min  
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56 4 for *vastus lateralis* and *biceps femoris*, and at min 1, 2, 3 & 4 for *rectus femoris* and *gastrocnemius*  
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58 *medialis*.



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6 **DISCUSSION**  
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8 This study investigated the effect of posture on the rate of fatigue during high-intensity constant-load  
9 cycling exercise, and to our knowledge these are the first measurements of fatigue *during* cycling. There  
10 were two important findings. First, the rate of fatigue during high-intensity cycling at the same absolute  
11 power output was significantly lower in the upright compared with the supine posture. Second, this effect  
12 on fatigue was accompanied by a lower activation of muscles that act about the ankle, knee and hip joint.  
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20 *Performance and Fatigue*  
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22 Performance during high-intensity constant-load is significantly prolonged during the upright compared  
23 with the supine posture (Egaña et al. 2007). In the present study, the constant load exercise was performed  
24 at the same intensity (i.e. 80% ‘peak’ power), but with the incorporation of regular all-out efforts (i.e.  
25 ‘fatigue’ trials only). Despite this modification to our original protocol, the magnitude of the postural effect  
26 on performance in the present study was similar to that observed previously (Egaña et al. 2006; Egaña et al.  
27 2007), confirming that the assessment of fatigue did not affect the postural effect on performance.  
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36 Studies of isolated human limbs revealed that muscle fatigue is affected by the position of the limb relative  
37 to the heart. Tilting the human body upright reduced the rate of fatigue during moderate to high-intensity  
38 voluntary exercise involving the ankle dorsiflexors (Tachi et al. 2004) and plantarflexors (Egaña and Green  
39 2005, 2007), and lowering the arm below heart level reduced electrical stimulation-induced fatigue of the  
40 *abductor pollicis* muscle (Fitzpatrick et al. 1996). The present findings extend these observations to  
41 ‘whole-body’ exercise and demonstrate a large and significant reduction in the rate of fatigue during the  
42 upright compared with supine position.  
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51 In the present study, the incorporation of the 10 s all-out efforts was expected to alter the maximum time  
52 sustained during the constant load cycling at 80% PP in both postures, and in an attempt to quantify the  
53 contribution of the repeated all-out bouts on the time to failure at 80% PP additional fatigue tests at a  
54 workload designed to create minimum levels of fatigue (i.e. 20% PP) were performed. Thus, the exercise  
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4 time for the 20% PP fatigue test was limited to that achieved during the same test at 80% PP. The lack of  
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6 fatigue (i.e. rate of fatigue didn't differ from 0 in any of the postures) or postural effect on fatigue observed  
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8 during the fatigue tests at 20% PP show that repeated assessments of peak power don't induce significant  
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10 fatigue at least when exercise times are limited to those achieved during the 80% PP fatigue test at the same  
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12 posture. However, when this assessment of fatigue is incorporated into the high-intensity tests it  
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14 significantly reduces the time to failure and, thereby, suggests that it increases fatigue.  
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18 As in previous studies, this postural effect on fatigue occurred in the absence of any significant postural  
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20 effect on maximum force or power output prior to or at the onset of exercise. In the present study,  
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22 differences in fatigue were evident at the second minute of exercise, confirming that the postural effect on  
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24 fatigue is relatively rapid and manifest within the first minute or two of exercise (Egaña and Green 2005,  
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26 2007; Fitzpatrick et al. 1996; Tachi et al. 2004). The most likely mechanism underpinning this postural  
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28 effect is muscle blood flow, which is affected during the first few seconds of exercise (Egaña and Green  
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30 2005), and its effect on the dynamic response of  $\dot{V}O_2$  (Convertino et al. 1984; Egaña et al. 2006; Koga et al.  
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32 1999; Leyk et al. 1994; MacDonald et al. 1998). However, further studies are required to clarify the  
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34 mechanisms involved and, particularly, the nature, extent and time-course of metabolic and ionic changes  
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36 in contracting muscle linked directly to the postural effect on fatigue.  
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#### 41 *Electromyographic Activities*

42 Important to the understanding of fatigue and exercise tolerance during complex motor tasks such as  
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44 cycling is an assessment of activation patterns in muscles that generate torque and power output about all  
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46 key joints (Green et al. (in press)).  
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51 In the present study, EMG activities were assessed during two bouts of high-intensity exercise (upright and  
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53 supine) that did not incorporate the assessment of fatigue. This was done because a) EMG activities during  
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55 the fatigue tests may have been influenced by the 10s maximal all-out efforts and b) to our knowledge  
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57 EMG activities have not been analysed during upright and supine exhaustive constant-load cycling at same  
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59 absolute workloads. Times to failure during these bouts were significantly longer than those during which  
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4 fatigue was assessed, and so the temporal profiles of EMG and fatigue during upright and supine exercise  
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6 cannot be directly compared. The maximum EMG assessed during the 10 s all-out effort prior to constant-  
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8 load exercise was not significantly different between postures, consistent with similar maximum power  
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10 outputs during supine and upright cycling. In contrast, during high-intensity cycling (80 % peak power) the  
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12 NEMGs of four of the five muscles were significantly greater by 1-4 minutes into exercise during supine  
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14 compared with upright cycling. Moreover, there was a progressive divergence of the NEMG responses for  
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16 all muscles such that the values at failure were higher in the supine position. **The differences on EMG**  
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18 **responses among the muscles might point to different contributions among the muscles to the**  
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20 **postural effect on fatigue.** These findings are in agreement with a study conducted by Tachi et al (2004)  
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22 where the investigators observed significantly higher integrated EMG responses of the *tibialis anterior*  
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24 muscle at the end of a exhaustive intermittent dorsiflexion exercise at 50% MVC when the legs of the  
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26 participants were above compared with below the level of the heart (Tachi et al. 2004). The NEMG data in  
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28 the present study imply that there was a posture-induced divergence in muscle activation (motor unit  
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30 recruitment and/or rate coding) during the first few minutes of exercise. Such NEMG behaviour during  
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32 more intense exercise is commonly thought to represent a compensatory increase in motor unit recruitment  
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34 and/or rate coding in the presence of fatigue. Support for this interpretation lies in the fact that differences  
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36 in fatigue and NEMG responses between supine and upright positions were significant at a similar fraction  
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38 of the total exercise time.  
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42 In contrast to these observations, Denis and Perrey (2006) showed that the EMG activities of the *vastus*  
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44 *lateralis*, *rectus femoris* and *biceps femoris* muscles during high-intensity cycling at the same relative  
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46 intensity (posture specific VT plus 25W) were not affected by posture (Denis and Perry 2006). However,  
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48 when high-intensity constant-load exercise is performed at the same *relative* power output the time to  
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50 failure is not affected by posture (Egaña et al. 2006). Thus, the lack of differences in muscle activity shown  
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52 by Denis and Perrey are likely related to the lack of postural effect on fatigue and performance when  
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54 cycling at the same relative intensities.  
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59 **It is possible that the dynamic response of  $\dot{V}O_2$  may be linked to the postural effect on muscle fatigue**  
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4 and EMG. The amplitude of the primary or 'fast' phase of  $\dot{V}O_2$  during high intensity cycle exercise  
5 (i.e. above the VT) is increased by upright tilt, whereas the amplitude of the 'slow' phase which  
6 typically emerges  $\approx$ 1-2 min after the onset of exercise is decreased (Koga et al. 1999). This slow  $\dot{V}O_2$   
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and EMG. The amplitude of the primary or 'fast' phase of  $\dot{V}O_2$  during high intensity cycle exercise (i.e. above the VT) is increased by upright tilt, whereas the amplitude of the 'slow' phase which typically emerges  $\approx$ 1-2 min after the onset of exercise is decreased (Koga et al. 1999). This slow  $\dot{V}O_2$  phase has been related to the recruitment of type IIb fibres that show slower time constant and greater O<sub>2</sub> cost of contraction and are recruited at higher intensities compared to type I fibres (Barstow and Mole 1991). The higher EMG responses observed in the supine posture are likely to be caused by additional recruitment of active motor units and/or increase in the rate of firing of active motor units in order to compensate to the higher motor unit fatigue in the supine posture (Tachi et al. 2004).

In the present study endurance and peak  $\dot{V}O_2$  were higher but muscle activities of the recorded muscles lower in the upright compared to supine posture. This is in agreement with the study by Tachi et al. (2004) where time sustained during a submaximal dorsi-flexion exercise was significantly longer while end-exercise EMG responses were lower when the legs were below the level of the heart compared to when the lower limbs were above the heart-level. We are unable to explain why end-exercise EMG responses in the recorded muscles were higher in the supine posture, but it is possible that other muscles involved in the task that were not recorded may have displayed different behavior and thus, contribute to the differences in peak  $\dot{V}O_2$  between postures.

In conclusion, the present study revealed that fatigue *during* high-intensity cycling is lower when performed in the upright compared with supine position, and that the divergence in these fatigue responses occurs by the second minute of exercise. In addition, EMG activities of muscles that act about the hip, knee and ankle joints increase at a greater rate during exercise in the supine position and achieve significantly higher values at task failure.

#### **ETHICAL STANDARDS:**

The experiments presented in the present study comply with the current laws of the Republic of Ireland.

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**CONFLICT OF INTEREST:**

The authors of the present study declare that they have no conflict of interest

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4 **FIGURE CAPTIONS:**  
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8 **Fig 1:** Individual normalised fatigue responses (% peak power) under the four exercise conditions.  
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11 **Fig 2:** Mean ( $\pm$  SD) rate of fatigue responses under the four exercise conditions.  
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14 **\*Significantly different from upright 80% Peak Power ( $P < 0.05$ )**  
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18 **Fig 3:** Mean ( $\pm$  SD) normalised responses of fatigue (% peak power) during the 80% PP fatigue tests in the  
19 upright and supine postures (times are limited to the worst performer, n=11).  
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22 **\*Significantly different from supine ( $P < 0.05$ )**  
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26 **Fig 4:** Mean ( $\pm$  SD) peak rms responses for all five muscles.  
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30 **Fig 5:** Mean ( $\pm$  SD) NEMG responses (% peak) for all five muscles during the EMG constant load tests at  
31 80 % PP in the supine and upright postures (times are limited to the worst performer; n = 11 for VL & RF;  
32 n = 9 for MG & GMax and n = 4 for BF).  
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36 **\*Significantly different from upright ( $P < 0.05$ )**  
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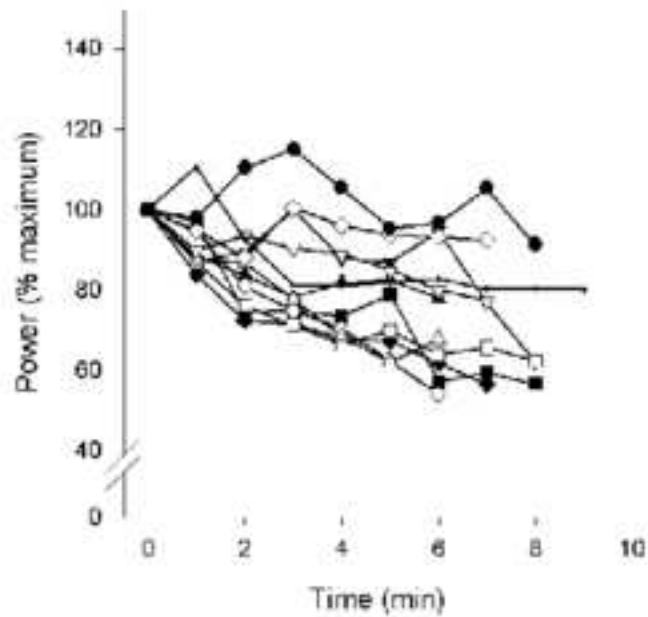
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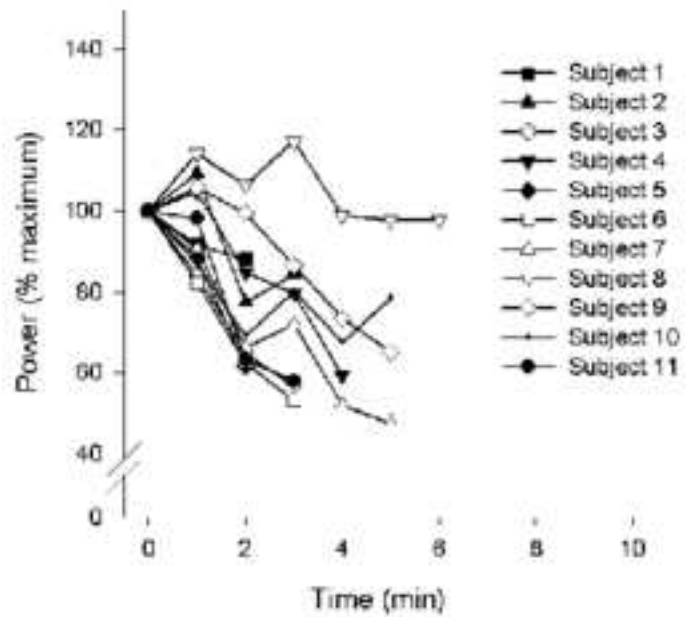
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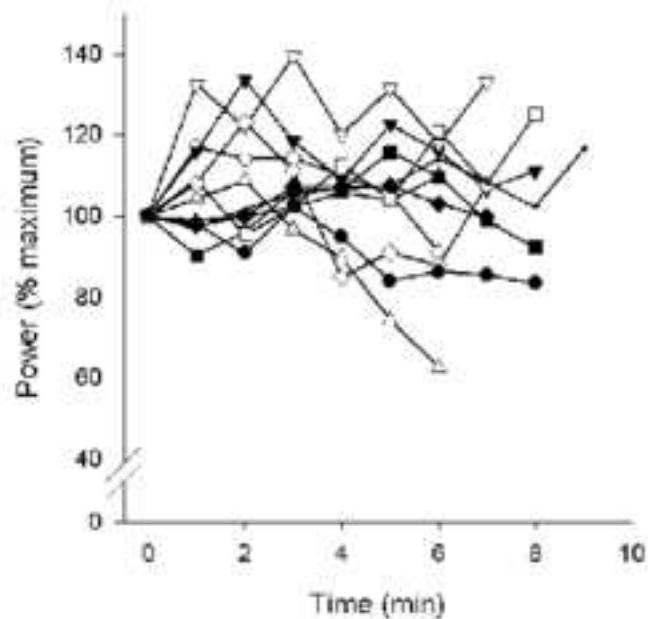
80% PP Upright



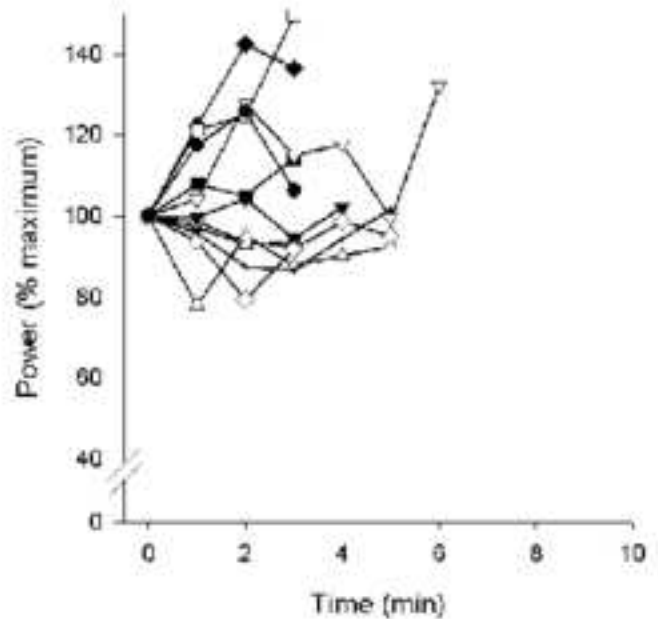
80% PP Supine

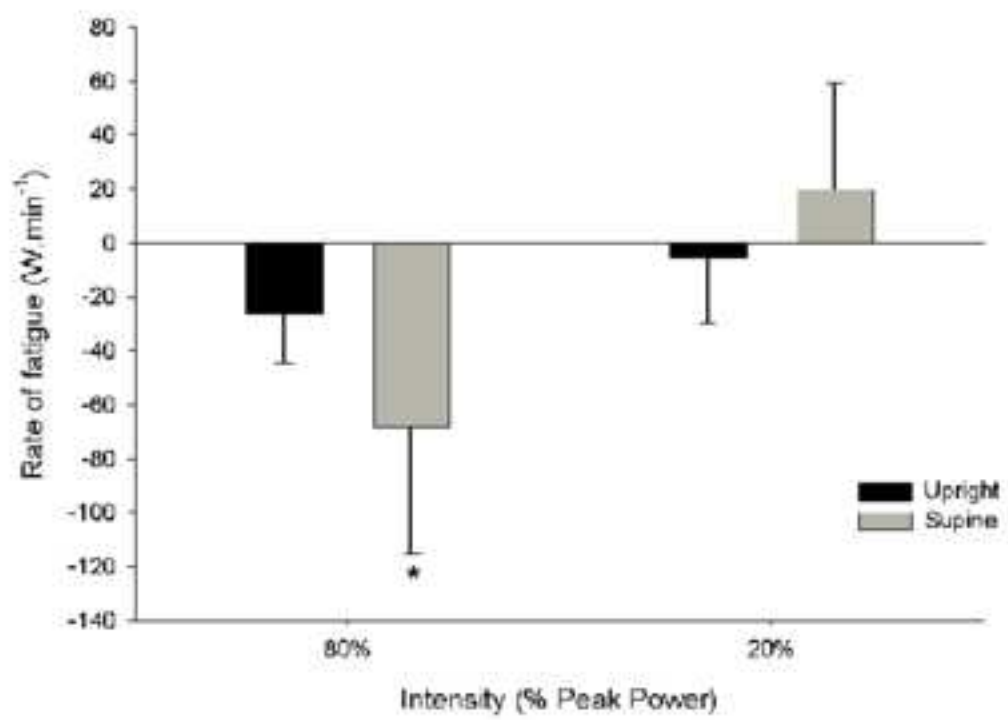


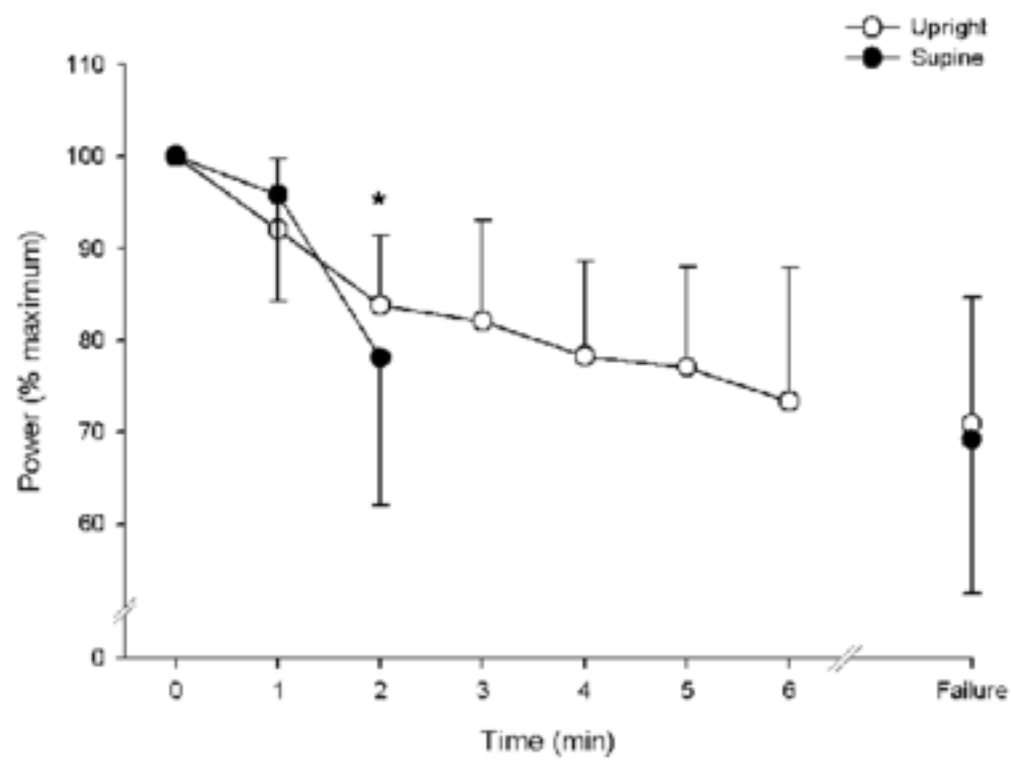
20% PP Upright

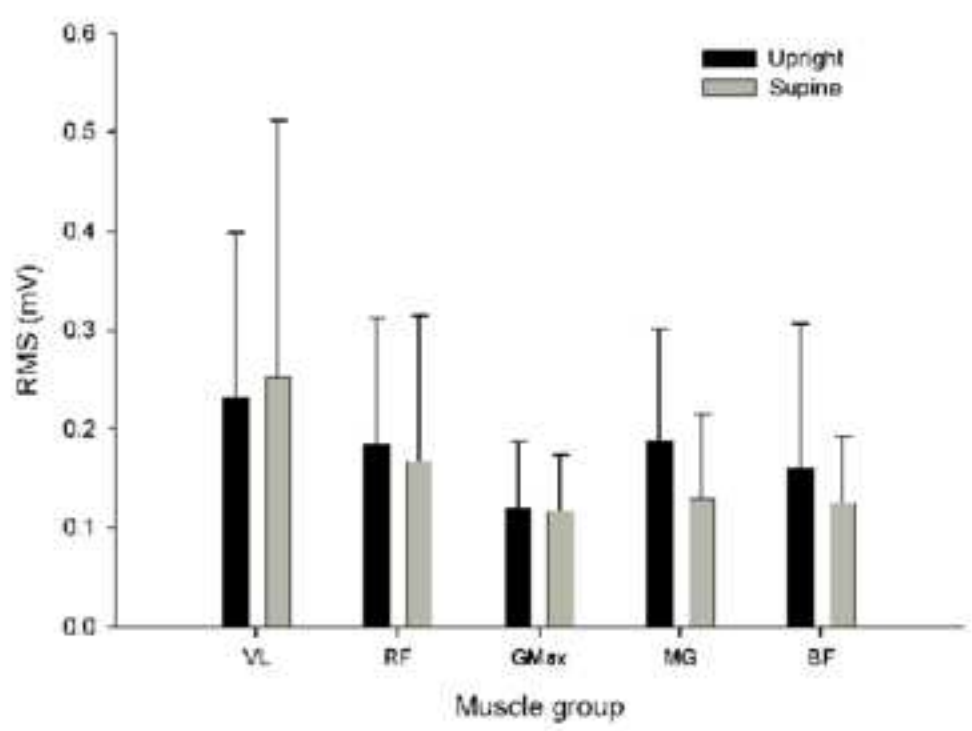


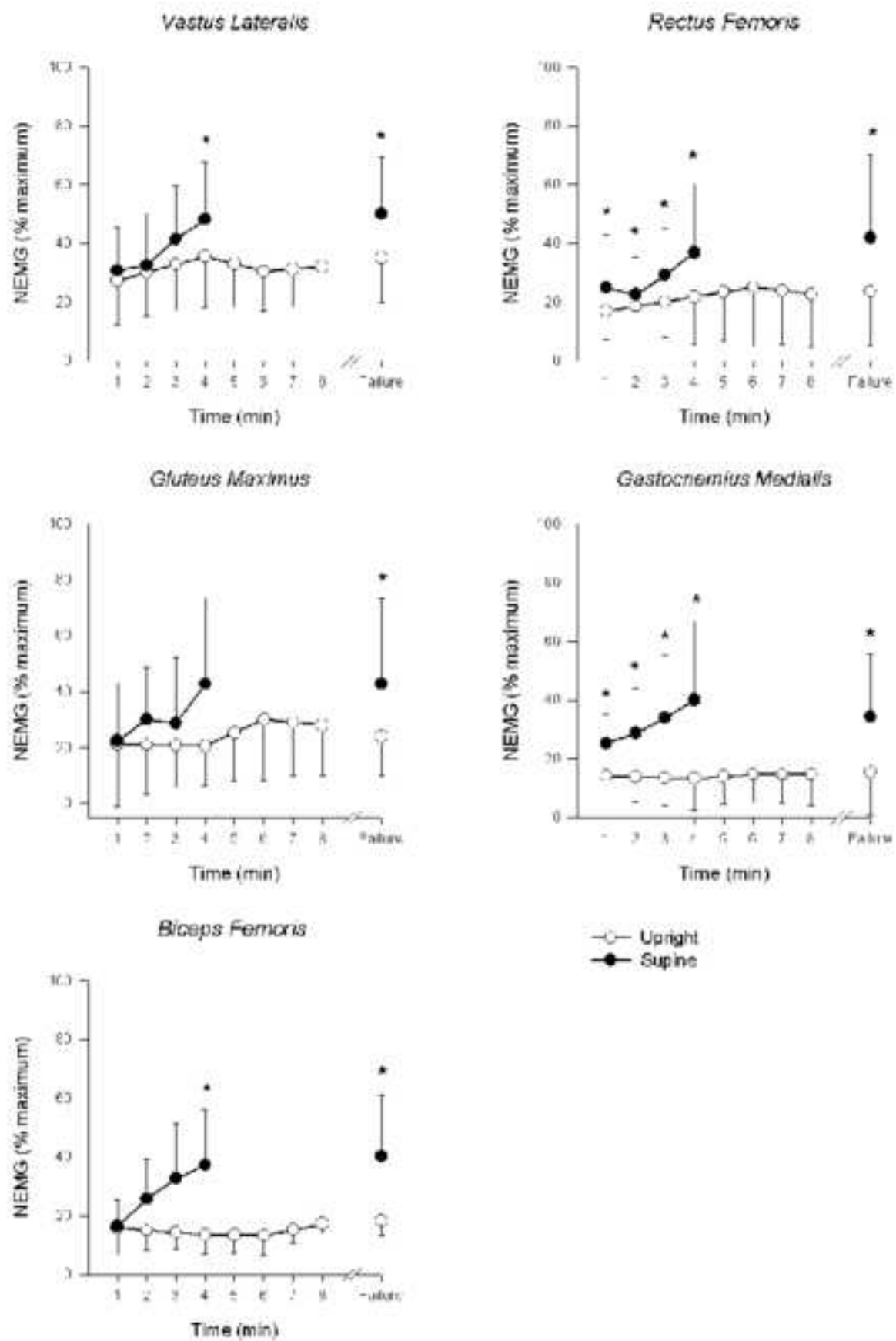
20% PP Supine











**Table 1 Summary of the experimental protocol. See methods for further details.**

	<b>Day 1</b>	<b>Days 2 &amp; 3</b>	<b>Day 4</b>	<b>Days 5 &amp; 6</b>
<b>Exercise performed</b>	<b>Graded test</b>	<b>Fatigue test (80% peak power)</b>	<b>Fatigue tests (x2) (20% peak power)</b>	<b>Constant-load test (80% peak power)</b>
<b>Body position</b>	<b>Upright</b>	<b>Upright (x1) Supine (x1) (randomly on separate days)</b>	<b>Upright (x1) Supine (x1) (randomly 30 min apart)</b>	<b>Upright (x1) Supine (x1) (randomly on separate days)</b>

**Table 2:** Mean ( $\pm$  SD) exercise times and physiological responses during graded exercise ( $n = 11$ ).

	Upright
Cycle time (min)	20.6 $\pm$ 3.1
<b>Resting HR (beats.min<sup>-1</sup>)</b>	<b>86 <math>\pm</math> 7</b>
Peak HR (beats.min <sup>-1</sup> )	194 $\pm$ 8
Peak Power (W)	248 $\pm$ 36
Peak $\dot{V}_{O_2}$ (ml.kg <sup>-1</sup> .min <sup>-1</sup> )	54.7 $\pm$ 6.9
Peak $\dot{V}_E$ (ml.kg <sup>-1</sup> .min <sup>-1</sup> )	1,837 $\pm$ 241
Peak RER	1.18 $\pm$ 0.06
VT (W)	188 $\pm$ 35
VT (% Peak Power)	75 $\pm$ 9

**Table 3:** Mean ( $\pm$  SD) exercise times and physiological responses during Fatigue (a) tests EMG (b) tests at 80% PP ( $n = 11$ ).

a) Fatigue tests:

	Upright	Supine
Cycle time (min)	$7.3 \pm 0.3$ *	$3.9 \pm 0.3$
<b>Resting HR (beats.min<sup>-1</sup>)</b>	<b><math>90 \pm 9</math> *</b>	<b><math>76 \pm 14</math></b>
Peak HR (beats.min <sup>-1</sup> )	$189 \pm 8$ *	$170 \pm 12$

b) EMG tests:

	Upright	Supine
Cycle time (min)	$16.4 \pm 4.8$ *†	$4.9 \pm 0.8$ †
<b>Resting HR (beats.min<sup>-1</sup>)</b>	<b><math>84 \pm 11</math> *</b>	<b><math>77 \pm 8</math></b>
Peak HR (beats.min <sup>-1</sup> )	$183 \pm 10$ *	$166 \pm 10$
Peak $\dot{V}_{O_2}$ (ml.kg <sup>-1</sup> .min <sup>-1</sup> )	$51.4 \pm 9.8$ *	$46.6 \pm 9.5$
Peak $\dot{V}_E$ (ml.kg <sup>-1</sup> .min <sup>-1</sup> )	$1,875 \pm 550$ *	$1,486 \pm 440$
Peak RER	$1.08 \pm 0.09$ *	$1.16 \pm 0.07$

\* Significantly different from supine ( $P < 0.05$ )

† Significantly different from Fatigue test at same posture ( $P < 0.05$ )