DOI: 10.4025/jphyseduc.v28i1.2838

Original Article

EFFECTS OF SADDLE HEIGHT ON PERFORMANCE AND MUSCULAR ACTIVITY DURING THE WINGATE TEST

EFEITOS DA ALTURA DO SELIM NO DESEMPENHO E NA ATIVAÇÃO MUSCULAR DURANTE TESTE DE WINGATE

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ABSTRACT
This study aimed to analyze the anaerobic performance and muscle activation during a supramaximal cycling test at three different saddle positions. Twelve competitive cyclists completed an incremental cycling test and three 30-s Wingate tests in three different saddle heights (reference, downward, and upward), in a random order, on different days. The saddle height was individually shifted downward and upward (seeing 2.5% of the distance from the pubic symphysis to ground) from the reference position. The electromyographic signal (EMG) data was obtained from the rectus femoris, vastus lateralis, biceps femoris (long head), and gastrocnemius lateralis in order to assess muscle activation during the entire test. The anaerobic variables and the EMG data were divided into six consecutive windows of 5-s. The EMG signals were normalized by the first 5-s window of the reference position to provide the percentage changes throughout the test. The results suggest that during a 30-s Wingate test small changes in saddle height result in greater peak power output (reference=1380±241 W; downward=1497±175 W, p=0.036; upward=1491±225 W, p=0.049) and greater activation period for vastus lateralis (reference=33.6%, downward=33.2%, upward=35.0%; p=0.001) in comparision to rectus femoris (reference=24.5%, downward=25.2%, upward=23.7%), biceps femoris (reference=20.7%, downward=20.8%, upward=19.9%), and gastrocnemius lateralis (reference=21.2%, downward=20.8%, upward=19.9%). The results suggest that small adjustments in saddle height may affect the force-length relationship of the muscles of the lower limb, and consequently their recruitment pattern and their ability to generate force.
Keywords: Cycling. Fatigue. Anaerobic power.

RESUMO
O presente estudo teve como objetivo analisar o desempenho anaeróbio e a ativação muscular durante um teste de ciclismo supramáximo em três diferentes alturas do selim. Doze ciclistas competitivos completaram um teste incremental em cicloergômetro e três testes de Wingate de 30 s em diferentes alturas do selim (referência, baixa e alta), de forma randomizada, em diferentes dias. A altura do selim foi alterada para baixo e para cima a partir da posição de referência usando como parâmetro o valor referente a (± 2,5%) da distância da sínfise púbica até o solo. O sinal eletromiográfico (EMG) foi obtido dos músculos reto femoral, vasto lateral, bíceps femoral (cabeça longa) e gastrocnêmio lateral. As variáveis anaeróbias e os dados de EMG foram divididos em seis janelas consecutivas de 5 s. Os sinals EMG foram normalizados pela primeira janela da posição de referência para estipular as mudanças percentuais ao longo do teste. Os resultados sugerem que durante o teste de Wingate de 30 s pequenas alterações na altura do selim resultam em aumento da potência pico (referência=1380±241 W; baixa=1497±175 W, p=0,036; alta=1491±225 W, p=0,049) e maior período de ativação percentual para o vasto lateral (referência=33,6%, baixa=33,2%, alta=35,0%; p=0,001) em relação ao reto femoral (referência=24,5%, baixa=25,2%, alta=23.7%), bíceps femoral (referência=20,7%, baixa=20,8%, alta=19,9%) e gastrocnêmio lateral (referência=21,2%, baixa=20,8%, alta=19,9%). Os resultados sugerem que pequenos ajustes na altura do selim podem afetar a relação força-comprimento e, consequentemente, a capacidade de gerar força e o padrão de recrutamento muscular dos membros inferiores.
Palavras-chave: Ciclismo. Fadiga. Potência anaeróbia.

Introduction

Cycling is a sport that involves races ranging from only a few seconds to several hours[1–3]. Regardless of duration, at some point in the race cyclists have to perform sprints at maximal power output. The production of maximal power output in cycling is dependent on energetic factors and the interaction between the cyclist-bicycle complex[4,5], where alterations to bicycle geometry can have an effect on the muscle force-velocity and force-length relationships.

The main alterations in geometry which appear to affect physiological and biomechanical parameters are related to changes in seat tube angle[6,7], crank length[8], and saddle height[9–17]. Studies have reported divergent results regarding changes in saddle height. While Ericson *et al.*[18] and Chen and Huang[15] concluded that changes in saddle height do not affect forces applied to the pedals or muscle recruitment patterns, other studies point to the opposite direction. Diefenthaeler *et al.*[12] observed that 1 cm changes in saddle height from the reference position resulted in significant changes in kinematic and electromyographic cycling parameters. These muscle recruitment findings corroborate others' findings[10,13]. All of these studies used submaximal protocols, which compromises the extrapolation of results to sprint race situations. Studies that have manipulated saddle height during the Wingate test[11,16] showed that a higher saddle height (i.e., 25º of knee flexion when the pedal is in the 6 o'clock position) tends to be beneficial for anaerobic performance. However, little is known about muscle recruitment patterns when changes in saddle height are made during supramaximal intensities. The closest was a study from Ricard *et al.*[6]. These authors aimed to evaluate the effect of two seat tube angles (72º and 82°) on anaerobic performance and muscle recruitment patterns during the Wingate test. Although these authors did not report hip angles, it is known that this angle may change when greater seat tube angles are used (i.e., 82°). The results of this study indicated that the use of greater angles did not compromise peak power, mean power and fatigue index, and resulted in lower biceps femoris muscle activity.

Previous results obtained at submaximal[10,13,19] intensities support the hypothesis that changes in bicycle geometry generate change in the neuromuscular recruitment pattern. To our knowledge, only Ricard *et al.*[6] have tested triathletes' anaerobic performance and muscle activation in differente bicycle geometry configuration at supramximal intensities. However, there is a lack of studies that compare both variables in different saddle heights at supramaximal intensities. Therefore, the objective of this study was to analyze anaerobic performance and muscle activity in competitive cyclists during the Wingate test performed at three different saddle heights. Our hypothesis is that small changes in saddle height can influence force output and muscle activation pattern during the Wingate test on a cycle ergometer.

Methods

Participants

Twelve competitive cyclists volunteered to participate in this study. All subjects had competitive experience (regional and national level). Subjects were fully informed of the risks and discomforts associated with the experimental procedures. All participants signed an Informed Consent Form in agreement with the Committee of Ethics in Research of the Institution where this study was conducted (nº 208/2011). The mean an standard deviation age, body mass, maximal oxygen uptake, and maximal power output were 31.7 ± 5.9 years, 73.8 ± 6.6 kg, 56.8 ± 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$, and 316.4 ± 35.6 W, respectively.

Experimental Procedures

Tests were performed in four different days, with an interval of 48 hours between them. On first day, cyclists were submitted to an incremental maximal cycling test to determine the aerobic variables. The protocol started at a workload of 100 W with increments of 30 W every 3 min until voluntary exhaustion. Also, first visit was used to perform a familiarization with the supramaximal test. The saddle height was individually set up to replicate the cyclists' bicycle configuration in terms of saddle and handlebar heights and horizontal position. This position was determined as the reference position. All volunteers were familiarized with experimental procedures. On subsequent days, randomly, cyclists performed a 30-s Wingate test[20] in three different saddle heights (i.e., reference, downward, and upward). All tests were performed on an electronically braked cycle ergometer (Excalibur Sport, Lode Medical Technology, Groningen, Netherlands).

Determination of saddle height

To guarantee similar conditions practiced during training and competitions, the settings on the cycle ergometer (i.e., saddle, cranks, and handlebars) were performed according to the cyclist position on his own bike before the Wingate tests. The saddle height was individually shifted downward and upward (seeing 2.5% of the distance from the pubic symphysis to ground) from the reference position (Figure 1).

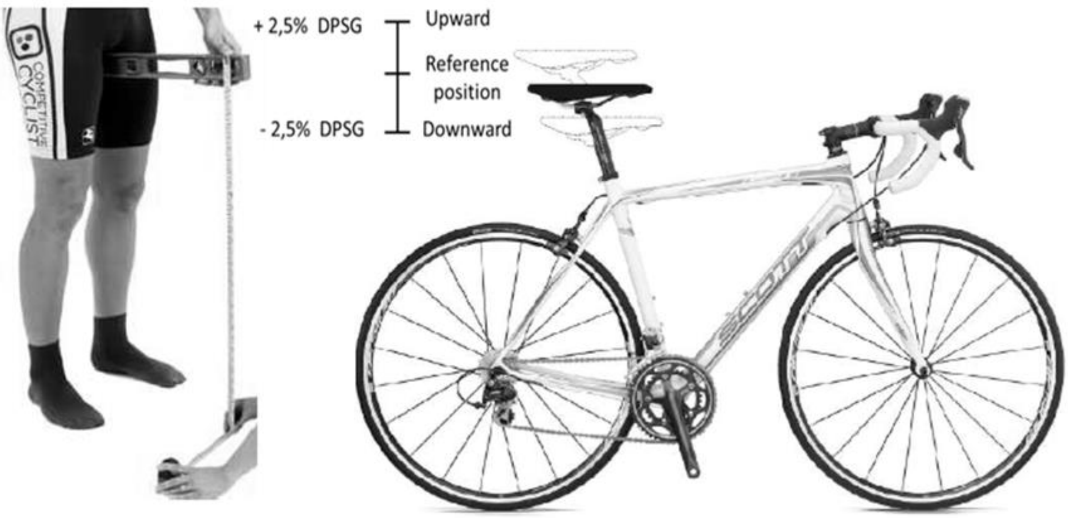

Figure 1. Saddle height calculated from the distance from the pubic symphysis to the ground (DPSG) and the three positions adopted during the Wingate tests: upward (+2.5% DPSG), reference position, and downward (-2.5% DPSG).
Source: Authors

Wingate test

During the 30-s Wingate test cyclists were instructed to remain seated on the saddle and to perform at maximal effort throughout the test[16]. The workload (i.e., resistance) used during the test was equivalent to 7.5% of the participant individual body mass[21]. Participants were verbally encouraged to perform at maximal effort during the entire test. The test was followed by 3 min of active recovery cycling at 50 W.

Muscle activity

Muscle activation was assessed by means of surface electromyography (EMG) from the right rectus femoris, vastus lateralis, biceps femoris (long head), and gastrocnemius lateralis. Signals were amplified and recorded at a sampling rate of 2000 Hz with 14 bit resolution using Miotool system (MioTec Biomedical, Porto Alegre, Brazil). Pairs of

Ag/AgCl electrodes (bipolar configuration) with a diameter of 22 mm (Kendall Meditrace, Mansfield, USA) were positioned on the skin after careful shaving and cleaning of the area with an abrasive cleaner and alcohol swabs to reduce the skin impedance. The position of all electrodes with respect to the muscle length and anatomic landmarks was recorded and also traced onto individual acetate sheet to ensure the same placement in each test over the experimental period.

Data Analyses

In order to indentify the anaerobic variables and analyze the EMG activity during the 30-s Wingate test the total time was divided into six consecutive 5-s epochs (i.e., 0-5; 5-10; 10-15; 15-20; 20-25, and 25-30 s). The peak power (P_{MAX}) was considered as the highest value observed during the first epoch. The mean power was obtained from the average of the six epochs, and minimum power (P_{MIN}) was obtained by the minimum value at the last epoch. The fatigue index was calculated by Fitzsimons *et al*.[22] formula [$IF=(P_{MAX}-P_{MIN}/P_{MAX})*100$].

The raw EMG signals were smoothed with a recursive 4th order band pass Butterworth digital filter at 20-500 Hz. After full wave rectification and offset correction, the onset and offset of EMG activity were determined by a mathematical criterion[23]. The onset of EMG was determined as being the signal with an amplitude above two standard deviations beyond mean of baseline value recorded during the contraction silent period. The root mean square (RMS) values of each epoch were used as an index of the total muscle activation, and between each 5-s interval. The EMG signal was normalized by the first epoch during the Wingate test at reference position. Furthermore, EMG signals were full wave rectified and then integrated (iEMG) and normalized according to the reference position. In order to calculate the overall percentage of muscle activation throughout the Wingate test, the iEMG from each muscle was divided by the iEMG sum of the four muscles. EMG data were stored on a personal computer and processed off-line using custom-made programs written in MATLAB® 7.1 (MathWorks Inc., Massachusetts, USA).

Statistical Analyses

Data are presented as means and standard deviations. Data normality, sphericity, and homocedascity were evaluated using Shapiro-Wilk, Mauchly, and Levene tests, respectively. Fatigue index and power output between saddle height positions were analyzed by one-way repeated measures analyses of variance. The RMS values for each muscle in each epoch was compared by means of a two-way ANOVA for repeated measures. The iEMG values for each muscle during the Wingate test was compared by means of an ANOVA for repeated measures. When main effects were significant, the Bonferroni post-hoc test was applied. The statistical analyses were realized using SPSS 15.0 for Windows (Statistical Package for the Social Sciences, Armonk, USA). A significance level of 0.05 was adopted for all the tests. Cohen’s effect size (ES) was computed for the analysis for anaerobic performance[24] and was rated as: < 0.2 trivial; 0.2 – 0.5 small; 0.5 – 0.8: moderate; > 0.8 large.

Results

Table 1 presents the anaerobic parameters obtained during the Wingate test at the three saddle height positions. It was observed a significant difference in absolute and relative peak power at reference position in comparison with downward and upward position ($p=0.036$ and $p=0.049$, respectively). However, no differences were observed for absolute and relative mean power at the end of the test ($p=0.176$ and $p=0.778$, respectively) and for fatigue index at the assessed positions ($p=0.257$).

Table 1. Mean and standard deviation of absolute peak power, relative peak power, absolute mean power, relative mean power, minimum power, and fatigue index in the three saddle position (reference, downward, and upward) during the Wingate test.

	Reference	**Downward**	**ES**	**Upward**	**ES**
Absolute Peak Power (W)	1380 ± 241*	1497 ± 175	0.48 (S)	1491 ± 225	0.46 (S)
Relative Peak Power ($W \cdot kg^{-1}$)	17.6 ± 3.4*	19.4 ± 1.9	0.52 (M)	19.5 ± 2.2	0.55 (M)
Absolute Mean Power (W)	691 ± 94	680 ± 94	-0.11 (T)	699 ± 83	0.08 (T)
Relative Mean Power ($W \cdot kg^{-1}$)	9.2 ± 0.6	9.1 ± 0.8	0.16 (T)	9.3 ± 0.7	0.16 (T)
Minimum Power (W)	556 ± 66	547 ± 62	0.10 (T)	563 ± 68	-0.14 (T)
Fatigue Index (%)	58.9 ± 6.7	63.4 ± 2.6	0.67 (M)	62.0 ± 3.6	0.46 (S)

*Statistical difference between upward, and downward saddle height; ES=effect size; T=trivial; S=small, M=moderate; SD=standard deviation.
Source: Authors

The different saddle heights influenced muscle activity during the Wingate test (p=0.001), as observed at Figure 2. At reference position vastus lateralis (p=0.001) and gastrocnemius lateralis (p=0.001) activation were lower when compared with upward and downward saddle height. However, rectus femoris and biceps femoris activation at upward position showed higher acitivation in comparison with downward (p=0.001) and reference (p=0.007) position.

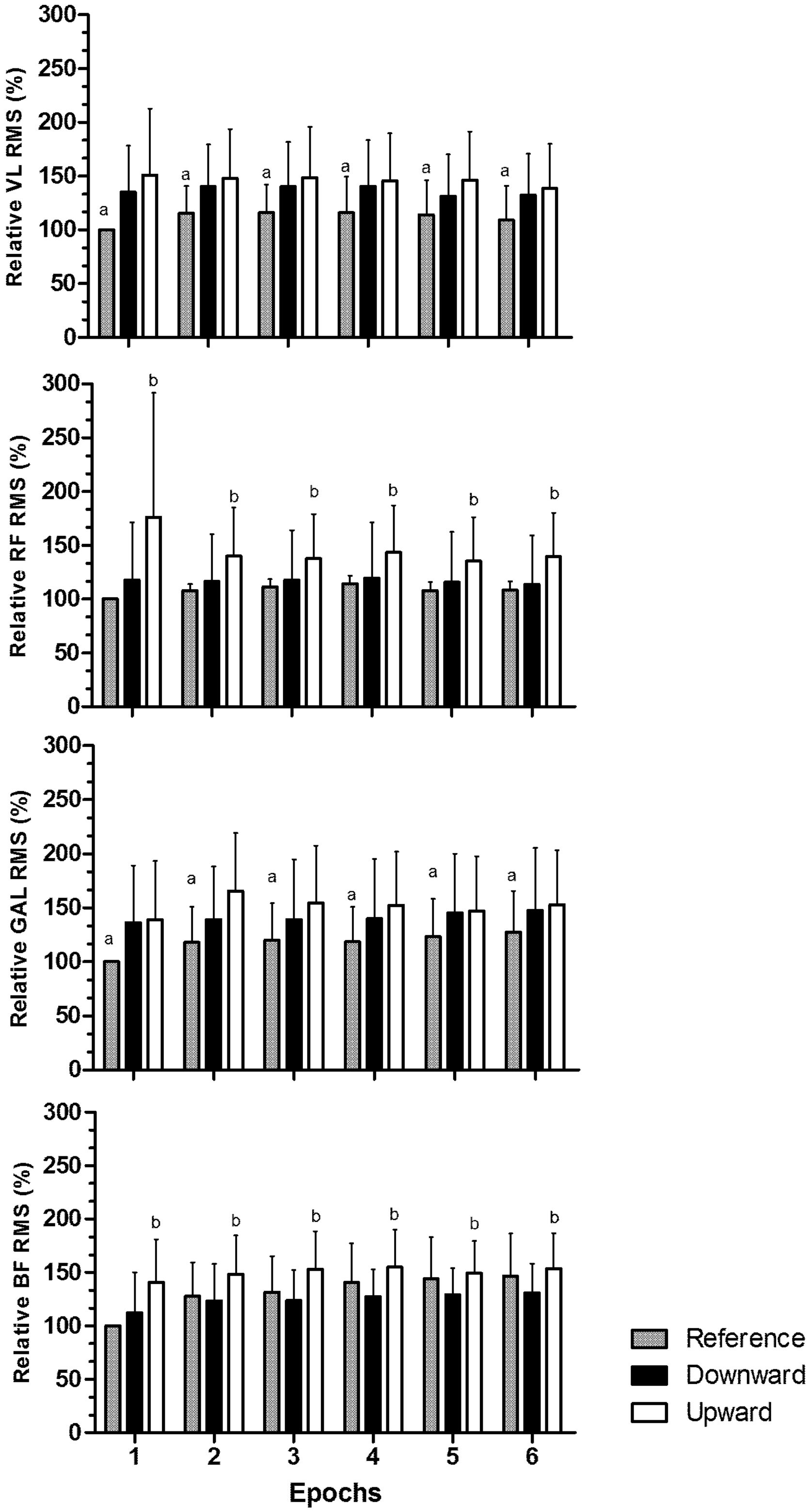

Figure 2. RMS values normalized by the first epoch for vastus lateralis (VL), rectus femoris (RF), gastrocnemius laterais (GAL), and biceps femoris (long head - BF) at reference, downward, and upward positions during the Wingate test. (a) Indicate statistical differences at downward and upward positions. (b) Indicate statistical differences at reference and downward positions ($p<0.05$).

Source: Authors

There were no significant differences on normalized iEMG of the evaluated muscles when compared with the reference position (Figure 3). Although, in a qualitative way, it was observed that at upward position cyclists presented a higher activation for all muscles.

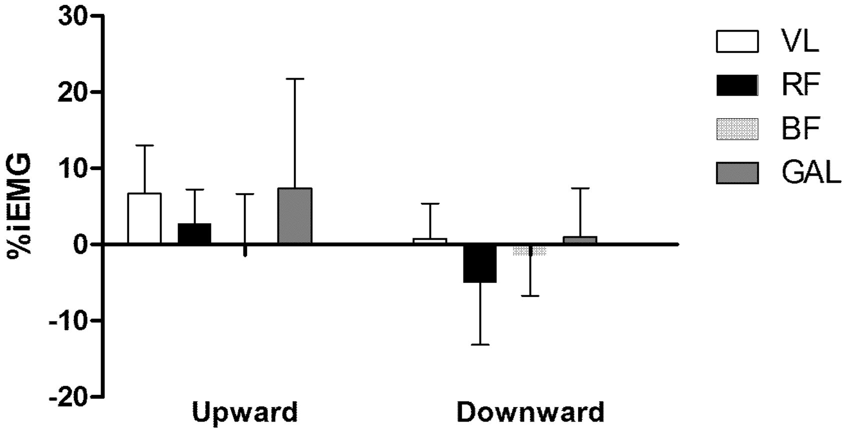

Figure 3. The percentenge of change on integrated EMG (iEMG) in relation with reference position (0%) for the muscles vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), and gastrocnemius lateralis (GAL) at upward and downward positions during the Wingate test.
Source: Authors

During the Wingate test the percentage of contribution of the vastus lateralis (reference=33.6%; downward=33.2%; upward=35.0%) was higher (p=0.001) in comparison with other muscles (rectus femoris: reference = 24.5%; downward = 25.2%; upward = 23.7%; biceps femoris: reference=20.7%; downward=20.8 %; upward=19.9%; and gastrocnemius lateralis: reference=21.2%; downward=21.2%; upward=20.7%). Moreover, rectus femoris also showed significant contribution, and these values were higher when compared with biceps femoris (p=0.014) and gastrocnemius lateralis (p=0.049) at the same saddle height.

Discussion

The objective of this study was to analyze anaerobic performance and muscle activity during Wingate tests completed by competitive cyclist at three different saddle heights. The main results of this study demonstrated that saddle height changes of 2.5%, upward or downward, relative to the reference position, resulted in larger peak power and muscle activation, especially at the high saddle heigth.

There is a consensus regarding the importance of anaerobic power as a decisive factor in track cycling[25] and road cycling[26] that involves ascents and sprints at the end of the race. Therefore, the Wingate test is one of the most used tests for anaerobic assessment[27]. Power output produced by the cyclist is dependent upon the force applied to the pedals and velocity (i.e., cadence), which can be influenced by changes in the cyclist-bicycle complex. This is because changes in geometry, especially in seat height, affect the length at which muscles produce force, thus changing the force-length and force-velocity relationships and the joint movement amplitude[17]. Something that can be taken into consideration in relation to changes in the force-length relationship and, consequently, in the patterns of muscle activation, is that seat height changes generate variations in the knee and ankle joints[28].

Peveler *et al.*[16] tested the effect of three different seat heights (25º and 35º knee angle with the pedal in the 6 o'clock position and 109% of the symphysis pubis height) on movement economy and performance during the Wingate test in trained cyclists. Their results indicated that pedaling with the seat in a higher position (25º) resulted in larger peak power when compared to 109% of the symphysis pubis height, and larger mean power compared to the 35º angle. From a methodological standpoint, our study differs from this because it took into consideration the seat height at which the cyclist is accustomed to pedaling (reference position). Diefenthaeler *et al*.[12] suggested that the maintenance of a specific seat height by the cyclist during training can produce specific adaptations in muscle properties. This reinforces the need for research protocols to replicate the geometry which cyclists use during training and competition.

As was reported by Peveler *et al*.[16], in the present study a larger peak power was also observed when cyclists pedaled at a higher saddle position. Furthermore, lowering the saddle height ciclists also generated significantly higher peak power compared to the reference position, without changes to the fatigue index for both saddle heigths (Table 1). Therefore, considering anaerobic performance as a set of variables analyzed, both saddle height changes resulted in better outcomes. The reasons for better anaerobic performance at lower and higher saddle position are not fully elucidated, but it can be speculated that such a change may produce alterations in the optimal angles for force production[29]. Due to specific adaptations in muscle properties we expected better anaerobic performance at the reference position, which was not confirmed. We suggest that saddle height should be chosen by taking into consideration other factors such as comfort[30] and pedaling technique[19]. However, these aspects were not evaluated in the present study.

The present study is the first to our knowledge that investigated the effects of saddle height changes on the electromyographic responses of lower limb muscles during the Wingate test. Two analyses were performed to facilitate comprehension, where the first was segmented into six 5-s windows and the second obtained from the average during the 30-s test. When analyzed in a segmented manner, the main results indicate that the reference position used by the cyclists during training and competition showed the lowest levels of muscle activation. On the other hand, the high saddle position showed larger activation in all muscles tested during all 5-s epochs compared to the reference saddle position, and the low position differed from the biceps femoris and rectus femoris. Our results for biceps femoris at upward position are contrary to the results found by Ricard *et al*.[6], who showed lower muscle activity when the seat tube angle was high (82º). However, in the study by Ricard *et al*.[6], there was no accurate knowledge of the magnitude of these changes since the changes in saddle height were due to changes in the seat tube angle (from 72º to 82º).

Regarding the total muscle activation analysis no significant differences were observed when the four muscles were compared (intra-muscular comparison) at different saddle heights relative to the reference position (Figure 3). However, there was a tendency toward greater activation of all muscles evaluated at the higher saddle position. Although not statistically significant, the slightly higher activation of all muscles in the high position may be the explanation for the maintenance of a slightly larger mean power (~3%, $p>0.05$) in the high compared to the low saddle position. Nonetheless, when the overall percentage of activation were compared significant differences were observed, where the vastus lateralis had the largest participation followed by rectus femoris, biceps femoris, and gastrocnemius lateralis. Hug and Dorel[31] reported that the vastus lateralis is a muscle that exclusively participates in the propulsive phase of the pedaling cycle (0°–180°) and its main function is to produce power since it is a single joint muscle[32]. On the other hand, the rectus femoris acts in the propulsive and recovery (180°–360°) phases[31], and its main function is to transfer muscle power since it is a biarticular muscle. Thus, as expected small adjustments in saddle height (±2.5%) were sufficient to change muscle activation pattern and percentage of participation of the muscles responsible for the propulsive phase of the pedaling cycle (i.e., vastus lateralis and rectus femoris).

All of the studies that tested the relationship between muscle activation and saddle height used submaximal protocols[10,13]. The results of these studies indicated that a low saddle height in relation to the reference position induced lower muscle activity in the soleus and gastrocnemius medialis[13], and increased electrical activity in the knee extensor and flexor muscles[10]. However, the use of maximal effort protocols such as the Wingate test could alter these behaviors, preventing comparisons between submaximal and maximal tests.

One limitation of the present study was that the EMG signals were not synchronized with the crank position. This would be important to identify changes in activation during the pedaling cycle during the test. Furthermore, it is known that during competition sprints, cyclists adopt a posture in which there is no contact with the seat. Our data may provide useful information about alterations to recruitment pattern as a result of changes in saddle height. Future studies involving changes in saddle height are necessary, especially in simulated races where there is an interchange between submaximal and maximal intensities.

Conclusion

The reference position adopted by cyclists during training and competition may not be ideal for maximal anaerobic performance. The results suggest that small adjustments in saddle height may affect the force-length relationship of the muscles of the lower limb, and consequently their recruitment pattern and their ability to generate force.

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Acknowledgments: Capes-Brazil and CNPq-Brazil for financing support.

Received on Nov, 27, 2015.
Reviewed on Aug, 29, 2016.
Accepted on Feb, 02, 2017.

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