EXTERNAL WORK BILATERAL SYMMETRY DURING INCREMENTAL CYCLING EXERCISE

Rodrigo Bini[*,*], Fernando Diefenthaler[*,**], Felipe Carpes[*,***], Carlos Bolli Mota[***]**

***Exercise Research Laboratory, UFRGS, Porto Alegre, Brazil**
****Human Performance Laboratory, UT, Austin, USA**
*****Biomechanics Laboratory, UFSM, Santa Maria, Brazil**

The aim of the present study was to compare the bilateral external work and torque at four stages of an incremental maximal cycling. Eleven cyclists were evaluated on a cycle ergometer. Four stages of the incremental cycling workload were defined as 60, 75, 90 and 100% of maximal oxygen uptake (VO_{2Max}). Pedal forces and kinematics variables were measured through each stage. Crank torque and external work were computed (both sides). Crank work and torque increased throughout the incremental test. There were no differences between legs in relation to work and torque at the crank. The high variability of force symmetry between subjects, and between days may indicate the difference of our results compared to previous studies.

KEY WORDS: fatigue, interlimb coordination, performance

INTRODUCTION:

The analysis of bilateral pedaling symmetry is important for a variety of reasons, including the measurement of the risk of overuse injuries and premature fatigue (Smak et al., 1999). The evaluation of pedal force symmetry has been suggested (Dal Monte et al., 1973), however, most of cycling research has been developed to verify the kinetics and kinematics variables in a single leg (Sanderson & Black, 2003). Smak et al. (1999) have evaluated bilateral pedal force of competitive cyclists at different cadences and fixed power output (PO), suggesting a high variability of the average PO between legs and asymmetry dependent on pedaling cadence. Hunt et al. (2003) observed symmetry of the linear impulse of the resultant pedal force for healthy uninjured subjects' legs. Carpes et al. (2007) have observed a reduction of bilateral crank torque symmetry with the increase of PO during a 40 km cycling time-trial. Unilateral pedal force and kinematics during incremental cycling have been described by Black et al. (1993). They indicated an increase of pedal force and a different pattern of pedal kinematics among subjects. The measurement of external work should indicate the behavior of joint work, and it has been described to be quite similar to the total joint work (Kautz et al., 1994). However, there is no study regarding bilateral joint work measurement, nor bilateral external work, and its relation with workload during incremental cycling. Considering the analysis of aforementioned investigations, there is a lack of studies regarding the evaluation of crank bilateral torque and work during incremental cycling. Herewith, the aim of the present study was to compare the bilateral external work and crank torque at four stages of an incremental maximal cycling.

METHOD:

Data Collection: Eleven male cyclists with mean age of 31 (SD 7) years, body mass of 74 (SD 8) kg, VO_{2Max} of 61 (SD 5) $ml \cdot kg \cdot min^{-1}$, more than five years of cycling experience, and peak power output of 407 (SD 36) W were evaluated on a cycle ergometer (Excalibur Lode, The Netherlands) with pedalling cadence between 80 and 100 rpm. Four stages of the incremental cycling workload were defined as 60, 75, 90 and 100% of maximal oxygen uptake (VO_{2Max}), as described by Coyle et al. (1988). All subjects cycled ten minutes to warm-up before the beginning of the test. Pedal forces were measured with two 2D pedal dynamometers (Newmiller et al., 1988, Figure 1) and bilateral kinematics were recorded with a video-based motion analysis (Vicon 612 motion system, *Oxford Metrics*, England) by six cameras (Figure 2). Pedal dynamometers were calibrated previously to evaluation session. Reflexive markers were located at the pedal spindle, and in the anterior and posterior pedal stick of both lower limbs. Pedal forces and kinematics were recorded at Vicon system workstation 64-channel A/D board (Vicon 612 Motion System, *Oxford Metrics*, England) with a sample frequency of 1080 and 120 Hz, respectively. All variables were recorded simultaneously for one minute at each stage of the incremental test.

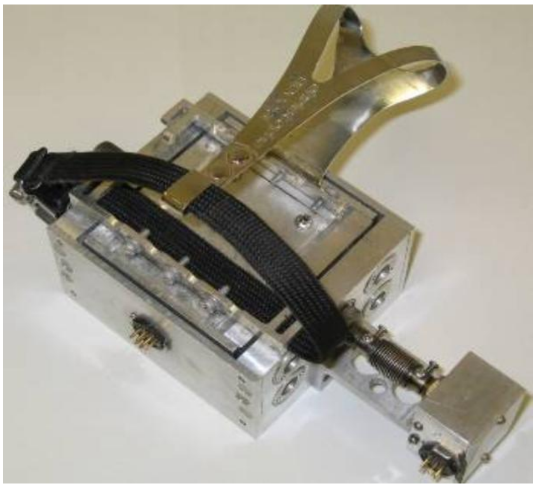

Figure 1 Right 2D pedal dynamometer. Newmiller et al. (1988).

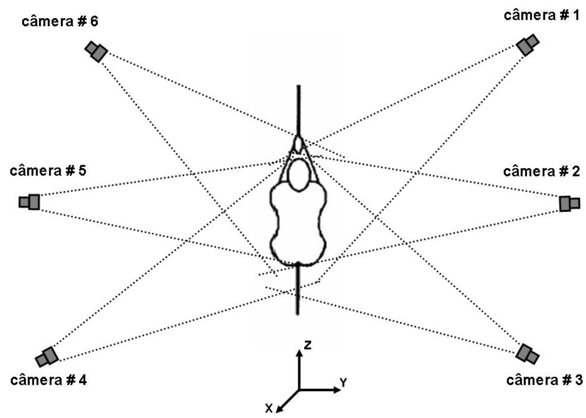

Figure 2 Six cameras' positioning in relation to the cycle ergometer.

Data Analysis: Pedal forces were down sampled to 120 Hz for data analysis. From the effective component of the resultant force applied to the pedals crank torque and power were computed (both sides). Calculation of external work was employed as the sum of crank work for both pedal power output throughout the crank cycle. The data analysis was performed in a Matlab's routine. External work and mean torque of both cranks were analysed for 15 consecutive pedalling cycles. The mean and standard deviation (SD) were reported for all variables. A two-way ANOVA was employed for the comparison of each stage (first factor) work and torque between limbs (second factor). *Post-hoc* analysis where the main effects or interactions were significant was performed using LSD *post-hoc*. The level of statistical significance for all analyses was set at $p<0.05$ and $p<0.01$. The statistical package SPSS 12.0 (SPSS Inc., USA) was used.

RESULTS:

Cadence and PO are shown in Figure 3.

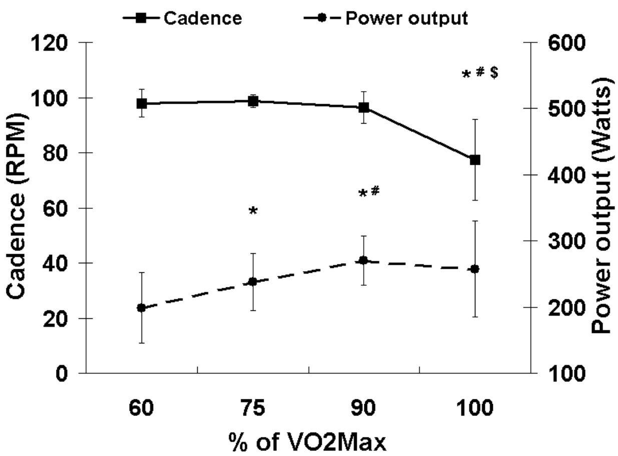

Figure 3 Cadence and power output at the four stages of VO_{2Max} test. * Indicates statistical difference in relation to 60% stage, # indicates statistical difference in relation to 75% stage, $ indicates statistical difference in relation to 90% stage.

Cadence has changed only in the last stage of the incremental test, with lower value compared to 60, 75 and 90% stages. Power output presented an increase at the 75 and 90% stages compared to 60% stage, while at the 100% there were no differences comparing to the other stages. Crank work and torque are shown in Figures 4 and 5, respectively.

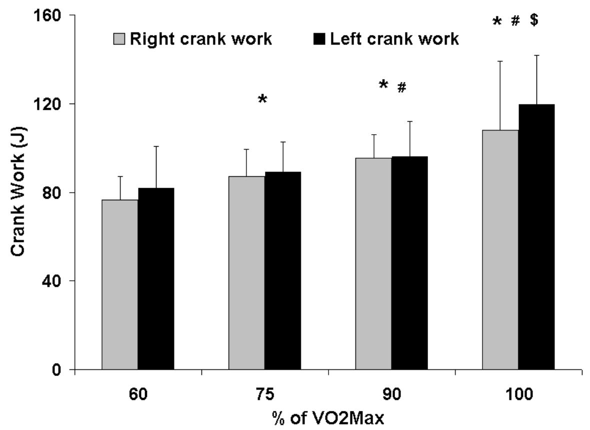

Figure 4 Crank work at the four stages of VO_{2Max} test. * Indicates statistical difference in relation to 60% stage, # indicates statistical difference in relation to 75% stage, $ indicates statistical difference in relation to 90% stage.

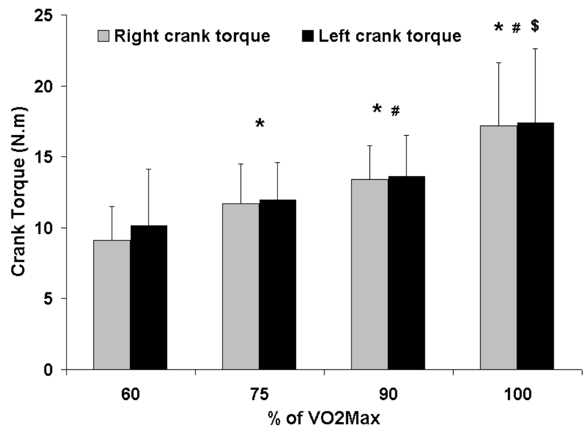

Figure 5 Crank torque at the four stages of VO2Max test. * Indicates statistical difference in relation to 60% stage, # indicates statistical difference in relation to 75% stage, $ indicates statistical difference in relation to 90% stage.

Crank work and torque increased throughout the incremental test. There were no differences between legs in relation to work and torque at the crank.

DISCUSSION:

The aim of the present study was to compare the bilateral external work and crank torque between the lower limbs at four stages of an incremental maximal cycling. The novelty of the present study was to analyze bilateral cycling pedal force and work symmetry during an incremental cycling exercise, because most of cycling pedal force evaluation was conducted as unilateral measurement (Sanderson & Black, 2003). Previous studies have described force asymmetry during cycling between 5 and 20% (Daly and Cavanagh, 1976; Sargeant and Davies, 1977; Hunt et al., 2003), which should include an additional error in the bilateral force assumption from unilateral force measurement. In the present study, the highest difference observed was about 3% for the last stage of the incremental test between legs, with no statistically significance. For walking and running the ground reaction forces may vary from 35% to 45% between the lower limbs (Hamill et al., 1984; Herzog et al., 1989), which should indicate a lower force asymmetry during cycling movement compared to walking and running. Carpes et al. (2007) have described a reduction of bilateral torque asymmetry with the increase of the power output (PO) during a 40 km cycling time-trial. The authors have suggested that at higher PO there is an improvement of the coordination between limbs, in an attempt to avoid premature fatigue or injury. Our hypothesis, as observed by Carpes et al. (2007) was that there would have been a decrease of force and work asymmetry with the increase of workload (e.g. PO). However, there were no significant differences between these variables in our study, even at the lower workload (60% of VO_{2Max}). Two possibilities must be considered, the first is that we have evaluated road cyclists, while other studies have evaluated mountain bike cyclists (Carpes et al., 2007) or healthy subjects with no competitive experience in cycling (Hunt et al., 2003). The difference between pedalling technique by means of kinematics evaluation between road and mountain bike cyclists has been previously described (Carpes et al., 2006), and it should justify the aforementioned possibility. The higher pedal force application for mountain bikers should also influence force and work symmetry. The second possibility for the divergence between our results and the literature is that there is a high variability of symmetry on pedal forces, even for trained cyclists (Smak et al., 1999). Daly and Cavanagh (1976) have observed a high variability of torque symmetry between subjects (± 15%). They have suggested that the symmetry is independent of the leg dominance and its highly variable between days, which should make difficult any conclusion about the definition of force symmetry in subjects.

CONCLUSION:

This study identified that there is no difference between mean crank torque and bilateral work during incremental workload cycling exercise. The characteristics of road cycling force application compared to mountain bike should justify the differences of our data regarding previous studies (Carpes et al., 2007). The high variability of force symmetry between subjects (Smak et al., 1999), and among days (Daly and Cavanagh, 1976) may indicate the difference of our results compared to previous studies.

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Acknowledgement

The authors would like to thank Dr. Rick Neptune for lending the pedal dynamometers and Dr. Jonathan Dingwell for the help with kinematics evaluation.