EFFECTS OF DIFFERENT PEDALING POSITIONS BY DYNAMIC-FITTING ON MUSCLE FATIGUE AND ENERGY EXPENDITURE IN AMATEUR CYCLISTS

Chun-Kai Tang[1], Hsiu-Chen Lin[2], Ching Huang[2], Kai-Cheng Liang[2] and Yi-Fen Shih[1]

Department of Physical Therapy and Assistive Technology, National Yang-Ming University, Taipei, Taiwan[1]
Department of Physical Therapy, China medical university, Taichung, Taiwan [2]

Inappropriate cycling positions may affect muscle usage and raise the fatigue level or risk of sport injury. Dynamic bike fitting helps the cyclists select proper bikes and adjust them to fit their ergometry. The purpose of this study is to investigate how different “knee forward of foot” (KFOF) distances can influence the rate of muscle fatigue and the energy expenditure during long periods of cycling. Six amateur cyclists were recruited to perform the graded exercise testing with different pedaling positions at four KFOF distances (+20, 0, -20, and -40 mm). Our results revealed that the muscle fatigue level, oxygen consumption and respiratory exchange that were evaluated by the Surface EMG and portable energy metabolism system would be significantly increased with KFOF at 20 and -40 mm when compared to those with KFOF at 0 and -20 mm.

KEYWORDS: muscle fatigue, bike, cycling, pedaling position

INTRODUCTION: Cycling exercise has become more popular worldwide in recent years. Regarded as a means of transportation before, biking has now become a recreational activity and a type of competitive athletics. Lots of people take up biking and become professional or amateur cyclists. Due to the long distances of biking, lots of cyclists suffer various sport injuries, such as anterior knee pain, patellar tendinitis, iliotibial band friction syndrome, quadriceps tendinitis, Achilles tendon tendinitis, etc (Deakon, 2012). These injuries may be developed not only from the long periods of cycling, but also from the overuse of the muscles if inefficient pedaling positions are used. Inappropriate cycling positions may cause muscle fatigue faster, which would lead to chronic sport injuries. Therefore, it is significant to recognize pedaling positions that can decrease the rate of fatigue and help cyclists decrease injury rates and increase exercise performances.
As a key factor of endurance in cycling performances, efficiency is defined as the ratio of the power output to the energy expenditure (Joyner & Coyle, 2008). Crank cycle, a circle from the highest pedal position (0°, top dead center, TDC) to the lowest (180°, bottom dead center, BDC) and back to TDC (Hug & Dorel, 2009), can be divided into the first half as the accelerating phase and the second as the recovery phase. Efficiency in a crank cycle is associated with different pedaling force directions and thus crank torques, which resulted from different cycling positions and lead to the change of muscle activation and the level of muscle fatigue (Fintelman et al., 2015).
To have an appropriate cycling position, bike fitting, either static or dynamic type, is a good way to assess the posture during cycling. Static fitting includes anthropometry and bike angle measurements (Ferrer-Roca et al., 2012), such as the saddle height, saddle setback, seat tube angle, etc. Previous studies indicated that different static fitting parameters would change the level of discomfort, muscle activation and muscle fatigue (Bini et al., 2011; Bisi et al., 2012; Cannon et al., 2007; Duggan et al., 2017; Verma et al., 2016).
Dynamic bike fitting uses a motion capture system to record the joint positions and posture during cycling, which can reflect the real conditions better than the static fitting. Bike fitters can use the fitting results to choose the appropriate size of the bike and adjust the components of it (e.g., saddle height, saddle setback). After professional bike fittings, cyclists could decrease the level of fatigue and improve exercise performances (Deakon, 2012). The Retül system is a common-used commercial dynamic bike fitting system. The “knee forward of foot” (KFOF) parameter is defined as the vertical projection distance of the knee to the fifth metatarsal head at 90° of the pedaling cycle. It could influence the direction of the pedaling force and crank torque in the accelerating phase, and then affect the energy efficiency and

muscle fatigue (Cannon et al., 2007; Fintelman et al., 2015). However, it is a controversial parameter in the bike fitting industry, and the proper value for this parameter is still in debate. Most previous studies changed the bike dimensions in static fitting to investigate their effects on the muscle activation and muscle fatigue level. However, these changes would alter the positions of several body segments and obscure the understanding of which joint would influence the sport performance and muscle activation. The change of KFOF on the speical bike of the Retül system allows us to alter only one joint; this would facilitate the analysis of the changes of the single joint on the muscle activations.
The purpose of this study was to investigate the effects that different KFOF distances have on the rate of muscle fatigue and the energy expenditure during a long period of cycling.

METHODS: Six male amateur cyclists, who were capable of completing the Taiwan Wu-Ling highest point challenge (altitude change: 2800 m, distance: 53 km) in 4 hours, volunteered to participate in the study (age: 32.5 ± 2.7 yrs, 173.7 ± 1.5 cm, 72.0 ± 11.0 kg). They had to first answer the ACSM Health/Fitness Facility Pre-participation Screening Questionnaire and checked less than three items. A dynamic fitting bike (Retül Müve SL Dynamic Fit Bike) was used to control their cycling position, and only the KFOF parameter was changed during the experiments. The smart sensors (Delsys® Trigno Wireless System) was used to collect the data of the muscle activation levels from vastus lateralis (VL), vastus medialis (VM), semimembranosus (SM), biceps femoris (BF), gluteus maximus (GM), tensor fascia lata (TFL), medial gastrocnemius (Gastro) and tibialis anterior (TA) of the right leg. A portable energy metabolism system (COSMED K4b2) was used to collect the data of the oxygen consumption (VO_2) and respiratory exchange rate (RER) during the cycling exercise.
The KFOF distance was measured at the forward pedaling position of 90°during dynamic cycling, and set at +20, 0, -20, and -40 mm (the negative values indicate that the knee is behind the vertical line over the pedal spindle). The experiment was completed in four non-consecutive days with at least one day apart among them. The graded exercise test (GXT) after proper dynamic fitting was set starting from 120 W and increased 10 W every minute until the participant can no longer continue. During the test, each participant was asked to maintain the riding cadence at around 90 rpm. If the cadence was less than 80 rpm, the researchers would remind and encourage the participant. However, if the cadence dropped to less than 70 rpm, the test would be terminated. The myoelectric signals were recorded in the middle 30 seconds of every testing minute. The VO_2 and respiratory exchange rate (RER) were calculated breath by breath during the whole exercise testing.
The pedaling cycle was identified first by the thigh acceleration data collected by the smart sensor on VL. The 30-sec electromyographic (EMG) data was first band-pass filtered (10 to 500 Hz) and the median frequency (MF) of each muscle in each pedaling cycle was calculated and then averaged. The filtered EMG data was then also rectified, and the root mean square (RMS) values were calculated by using a moving window of 0.02 sec with 0.01 sec overlapped. Considering the capability of our cyclists, the maximal RMS values at 210 W were used for EMG data normalization. The peaks of the normalized RMS were extracted from the pedaling cycles, which were then averaged from the 30-sec data of every testing minute. The trend in the averaged RMS and MF of each testing minute during the GXT was represented by the slope of the regression line (Figure 1). SPSS (SPSS Inc.) was used for statistical analysis with the significant level set at 0.05. Friedman non-parametric test was used to compare the differences of RMS and MF among four different pedaling positions. One sample t-test was used to analyse the slopes of the RMS and MF to identify any significantly increasing or decreasing trends. Multiple regression was used to identify the predictive changes in VO_2 and RER when compared to the condition of KFOF at 0 mm.

RESULTS: The comparisons of the normalized mean RMS of the 8 various muscles among 4 pedaling positions showed no statistical significances. Figure 2 demonstrated several statistical significances in slope magnitudes of the RMS data during the GXT in 4 positions. The positive values of the slope indicated the increasing RMS magnitudes along with the increasing power output as the GXT progressed. With KFOF at +20 mm, the increasing trends were found in the VL, VM, SM and BF and GM muscles while the VM, BF and TFL muscles with KFOF at 0 mm, the VL, VM, SM, BF and GM muscles with KFOF at -20 mm, and the VL, VM, SM, BF and GM muscles with KFOF at -40 mm. The analysis of mean MF also showed no significant differences among the 4 positions in 8 various muscles. The slope of the MF during the GXT in the 4 positions (Figure 3) demonstrated that significantly increasing trends in the VL and BF muscles with KFOF at -40mm and the GM muscle with KFOF at -20mm.

The multiple regression analysis of VO_2 and RER used KFOF at 0 mm as a reference point to show the effects of the position changes. We can find that the VO_2 intercept with KFOF at 0 mm was -363.3, and with KFOF at +20 mm was -976.94 with statistical significances (Table1). This result indicates that KFOF at +20 mm may consume more oxygen during the GXT. The RER intercept with KFOF at 0 mm was 0.1718, and with KFOF at +20 mm and -40 mm was 0.26596 and 0.24748 respectively with statistical significances (Table 2). This result indicates that KFOF at +20 mm and -40 mm may make the anaerobic threshold (RER>1) be reached more quickly.

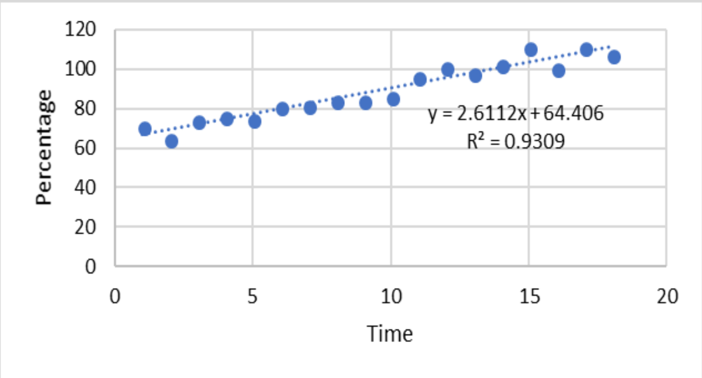

Figure 1. An example of a regression line of the RMS of BF with KFOF at -40 mm position

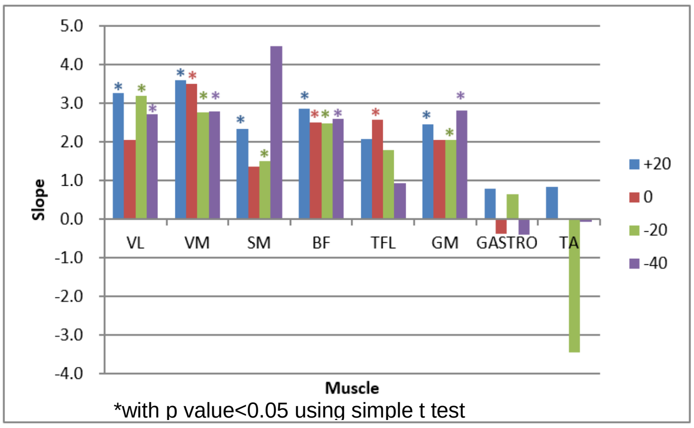

Figure 2. Slope of RMS in 4 different positions

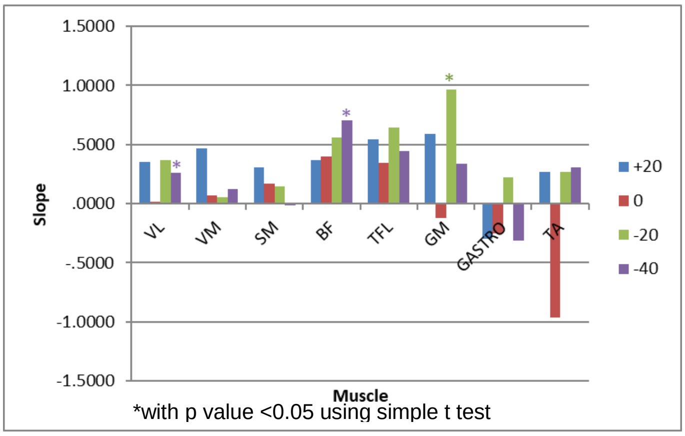

Figure 3. Slope of MF in 4 different positions

Table 1. Intercept of oxygen consumption

Pedaling position	Intercept	P value
-40 mm	-778.89	0.0570
-20 mm	-183.95	0.3867
+20 mm	-976.94	0.0061
0 mm	-363.30	0.0946

Table 2. Intercept of RER

Pedaling position	Intercept	P value
-40 mm	0.24748	0.0364
-20 mm	0.181126	0.7904
+20 mm	0.26596	0.0156
0 mm	0.1718	0.0029

DISCUSSION: The aim of this study was to investigate how the different KFOF distances can influence the rate of muscle fatigue during long periods of cycling. In this study, we analyzed the possible shift of the MF to show the muscle fatigue, but the results showed no significant tendency of the MF among different pedaling positions. We speculated that it may be owed to the increased power during the GXT which required recruiting more powerful muscle fibres (i.e. type II muscle fibres) resulting in a higher MF. Previous studies found that when the fatigue test was conducted by a same power, the MF was significantly decreased; however, there was no significant change in GXT (Bisi et al., 2012; Garside & Doran, 2000).

Our results showed the increasing trends of the MF in the VL and BF muscles and RER as the GXT progressed with KFOF at -40 mm. With KFOF at 20 mm, similar trends were found in the MF of the Gastro muscle, VO_2 and RER. The increased uses of the large muscles like the VL and BF muscles may require more VO_2, which may make it possible to reach the anaerobic threshold faster (Razanskas et al., 2015). No other studies use KFOF as a parameter to assess its effects on the cycling efficiency in the past. Previous studies changed the seat tube angle and saddle height to observe their effects on the level of muscle fatigue and metabolism. Some showed that the increased seat height (Bini et al., 2011) and seat tube angle (Garside et al., 2000) may result in muscle fatigue more easily. However, others (Bisi et al., 2012) showed no differences among the seat tube angle, muscle fatigue and energy metabolism. It indicates that the relationships among pedaling positions, muscle fatigue and energy consumption are still controversial. The results of this study showed that the extreme pedaling positions away from the vertical line, like KFOF at +20 mm or -40 mm, would be prone to result in muscle fatigue and increased energy expenditure.

CONCLUSION: In the pedaling positions of KFOF at +20 mm or -40 mm, cyclists may need larger muscle activations and more oxygen consumption, indicating a lower cycling efficiency and the proneness to result in fatigue faster. The pedaling positions with KFOF at 0 mm or -20 mm may be more effective pedaling for long-period cycling.

REFERENCES

Bini, R., Hume, P. A., & Croft, J. L. (2011). Effects of bicycle saddle height on knee injury risk and cycling performance. *Sports Med, 41*, 463-476.

Bisi, M. C., Ceccarelli, M., Riva, F., & Stagni, R. (2012). Biomechanical and metabolic responses to seat-tube angle variation during cycling in tri-athletes. *J Electromyogr Kinesiol, 22*, 845-851.

Cannon, D. T., Kolkhorst, F. W., & Cipriani, D. J. (2007). Effect of pedaling technique on muscle activity and cycling efficiency. *Eur J Appl Physiol, 99*, 659-664.

Deakon, R. T. (2012). Chronic musculoskeletal conditions associated with the cycling segment of the triathlon; prevention and treatment with an emphasis on proper bicycle fitting. *Sports Med Arthrosc, 20*, 200-205.

Duggan, W., Donne, B., & Fleming, N. (2017). Effect of Seat Tube Angle and Exercise Intensity on Muscle Activity Patterns in Cyclists. *Int J Exerc Sci, 10*, 1145-1156.

Ferrer-Roca, V., Roig, A., Galilea, P., & Garcia-Lopez, J. (2012). Influence of saddle height on lower limb kinematics in well-trained cyclists: static vs. dynamic evaluation in bike fitting. *J Strength Cond Res, 26*, 3025-3029.

Fintelman, D. M., Sterling, M., Hemida, H., & Li, F. X. (2015). Effect of different aerodynamic time trial cycling positions on muscle activation and crank torque. *Scand J Med Sci Sports*.

Garside, I., & Doran, D. A. (2000). Effects of bicycle frame ergonomics on triathlon 10-km running performance. *J Sports Sci, 18*, 825-833.

Hug, F., & Dorel, S. (2009). Electromyographic analysis of pedaling: a review. *J Electromyogr Kinesiol, 19*, 182-198.

Joyner, M. J., & Coyle, E. F. (2008). Endurance exercise performance: the physiology of champions. *J Physiol, 586*, 35-44.

Razanskas, P., Verikas, A., Olsson, C., & Viberg, P. A. (2015). Predicting Blood Lactate Concentration and Oxygen Uptake from sEMG Data during Fatiguing Cycling Exercise. *Sensors (Basel), 15*, 20480-20500.

Verma, R., Hansen, E. A., de Zee, M., & Madeleine, P. (2016). Effect of seat positions on discomfort, muscle activation, pressure distribution and pedal force during cycling. *J Electromyogr Kinesiol, 27*, 78-86.

ACKNOWLEDGEMENTS: We wanted to express our gratitude to all the participants and also the financial supports the Ministry of Science and Technology of Taiwan, and Chia Medical University.