Malaysian Journal of Ergonomics 2020, Vol. 2 (1): 39 – 49

ORIGINAL ARTICLE

Effect between cadence and lower extremity muscle activity during uphill cycling to cyclist performance

Yvonne Koay Ee Vorn[2], Ahmad Faizal bin Salleh[1,2], U.N.N. Abdullah[1,3],

Mohammad Shahril bin Salim[1,2], Hamzah Sakeran[1,2]

Sports Engineering Research Centre, Centre of Excellent (SERC), Universiti Malaysia Perlis, Perlis, Malaysia[1]

Faculty of Electronic Engineering Technology, Universiti Malaysia Perlis, Perlis, Malaysia[2]

Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis, Perlis, Malaysia[3]

ahmadfaizal@unimap.edu.my

Cycling is an exercise performing in a vertically reciprocating movement using bicycle which usually serves as sport equipment for training and as transport. Great quantity of lower extremity muscle contraction involved in uphill cycling. In the past few decades, research related to cycling includes study of lower limb muscle activity by various situation applied. However, few research studies on the lower limb muscle activation level with varying cadence during uphill cycling. Thus, this task proposes to investigate the effect of pedalling cadence and tilting angle of cycling on lower extremity muscle activity, and to compare the muscle activation level between genders. Three pedalling cadences (70rpm, 80rpm and 90rpm) and two tilting angles of cycling inclination (10° and 30°) were set. Electromyography (EMG) measurements of the vastus lateralis and vastus medialis in quadriceps were done and collected from 5 males and 5 females during cycling. ANOVA analysis was performed, and results indicated that pedaling cadence had significant influence on the lower extremity muscle activity ($p < 0.05$). Increasing pedaling cadence caused a significant increase in the muscle activation of the vastus lateralis. For gender effect, females tend to have a higher muscle activation level and significantly greater vastus lateralis muscle activity than males during cycling. On the other hand, no significant differences in peak muscle activity at both tilting angles of cycling and no significant interaction effect in all group comparison.

Keywords: pedalling cadence, tilting angle, muscle activity

1.0 INTRODUCTION

Cycling performs in a vertically reciprocating movement which almost similar to walking. Therefore, it acts as an important role in fitness and rehabilitation centres [1]. Indeed, uphill cycling is more challenging than cycling along level land. To draw better in uphill cycling requires improvements of both strength-to-weight ratio and technical accomplishment. Uphill cycling involves a large amount of lower extremity muscle contraction as well as some movement of the body compared to normal cycling on the ground. During cycling, quadriceps is the major muscle group that brings forth energy. Therefore, vastus medialis and vastus lateralis muscle was considered in the study since both muscles produced a peak activity level while pushing down pedalling action [6, 26].

There are few studies concerned about the EMG readings when changing the slope and posture [2, 3, 4-6]. Lack of research on uphill cycling is because the difficulty in obtaining data during road cycling. However, the uphill cycling studies have conducted in the laboratory using classical Ergometers or treadmills reported in journals by Patterson and Pearson (1983); Kautz (1991); Swain and Wilcox (1992); Li and Caldwell (1998), Heil (1998) and Hansen (2002) [4, 7-11]. In these few decades, coordination and contractions of the lower extremity muscles during cycling has been experimentally investigated and theoretical studied related in forward dynamic simulation [12]. Hug and Dorel, they presented that various constraints such as pedalling cadence, riding posture, power output, shoe-pedal interface, seat height, training status and muscle fatigue would affect the coordination strategies [13] and muscle recruitment as well [14]. The significant difference in the torque profile was found when make comparison between flat terrain cycling at a cadence of 100 rpm and uphill cycling at a cadence of 60 rpm. It was found that the optimum cadence during uphill cycling should be lower than riding along the flat terrain [2]. Some subjects have indicated that using higher pedalling cadences could improve performance of cyclist. During uphill, higher pedalling cadence is used to reduce the muscle mass used to stabilize the trunk and a reduction of peripheral muscular and neuromuscular fatigue can be acquired by increasing the pedalling cadence [9, 11, 15-18]. Bertucci noted that the crank torque profile differences are minimal between level ground and uphill road cycling when the pedalling cadences remain the same [2]. A review of muscle activation does not statistically significantly change during cycling up the slope inclination of 4%, 7% and 10% with 80% of maximum aerobic power. Despite of insignificant changes of muscle activation when different tilt of slope during cycling yet it is likely influenced by cadence [19]. Nevertheless, surveys done by Clary, Alewaeters and Zinzen claimed that leg muscle activation increases generally while varying the inclination from 0% to 12% [20]. Their results refer to EMG patterns of the general leg muscles and not concerned onto individual muscles.

The aim of the present work is to look into the influence of pedalling cadences and tilting angles on lower arm muscle activity. To boot, the influence of different combination of pedalling cadences and tilting angles on lower limb muscle activities between genders was also searched.

2.0 METHOD

Subject

A group of 10 volunteered healthy (5 females, 5 males) subjects with normal Body Mass Index (BMI) (18.5 to 25 kg/m^2) without any historical injuries (ages 23.1 ± 0.57 years, weight 58.2 ± 8.24 kg, height 1.65 ± 0.07 m) participated in this study. Before the experiment, all subjects were informed around the protocol to be employed and gave written informed consent.

Experimental Equipment

Pairs of circular pre-gelled Ag/AgCl surface electrodes were employed in the experimentation. EMG sensors were conformed to recommendations of SENIAM. EMG measurement was recorded by using two channels of EMG system (AD Instrument Chart version 5 with PowerLab). All measurements were performed on a standard ergo bicycle mounted by magnetic sensor with portable digital LCD display speedometer (real-time display of cycle in revolution per minute (rpm)) (Fig. 1.).

Fig. 1. Ergo Bicycle used in the experiment

Protocol

Each cyclist performed two tasks in the laboratory. The first task was a maximum voluntary contraction (MVC) exercise to determine maximum muscle activation of each cyclist. It is a performance against static resistance to raise an effective maximum innervation of muscle. For exercise familiarization, a warm-up of the specific MVC exercise was performed and at least one practice contraction was completed. After warming up, subjects performed three trial of MVC, and three seconds were given to execute each trial. The subject was instructed to provide maximal efforts on each trial. The subject was given at least 1-minute rest period between each MVC testing. The first stage of the exercise was completed if the maximal steady state contraction was achieved, if not the subject was required to repeat the MVC exercise. Next, the subject was required to cycle with three different pedalling cadences which are 70, 80 and 90 rpm for two different tilting angles which are 10° and 30°. For each pedalling cadence and tilting angle, subject was given 20 seconds to cycle and three trials were performed. Meanwhile, the subject was given about 2 minutes to rest between trials to prevent muscle fatigue.

EMG was measured from vastus lateralis (VL) and vastus medialis (VM) using bipolar Ag/AgCl surface electrodes with an inter electrode distance approximately 2.0cm on the belly muscle (parallel to muscle fibres). The reference electrode was placed on inactive muscle site (knee). The EMG electrodes were placed on the left leg after removal of hair and cleaning with alcohol swab. All the electrodes and wires were fastened along the skin with adhesive pads to avoid relative movement causes artefacts. EMG signals were amplified, filtered through an analogue bandpass filter (20-450 Hz) and sampled at a frequency of 1 kHz [25]. Data collection occurred during the 20s of each pedalling trial.

Statistical Analysis

All analyses were performed with the JMP PRO 11 statistical program for Windows. The data were examined for normality and turned out to be not normality distributed. Hence, the transformation of data was performed for data normalisation. Two-way analysis of variance (ANOVA) was used to test the significant difference of each parameter (peak EMG, tilting angle, pedaling cadence and type of muscles) and Least Square (LS) Mean plot was used to reveal the trend of significant and significant interaction effect between parameter. The level of significance was set at 0.05.

3.0 RESULTS

Effect of pedalling cadence

Result of mean peak EMG activity across three different pedalling cadences conditions for all subjects is represented in Fig. 2. Statistically significant differences were shown in the pedaling cadence, F (dof) = F test value, $p < 0.05$. As expected, an increase in pedalling cadence causes greater contraction of lower extremity muscle, thus, the higher peak EMG value was generated.

For cycling, vastus lateralis (VL) showed a substantial increase in mean peak EMG activity with increasing pedalling cadence (Fig. 3). For vastus medialis (VM), the mean peak EMG activity increases as well but drastically lower compared to VL when increased of pedalling cadences during cycling at 70 rpm which only utilized 0.00104 mV (± std. Deviation 0.17). Only VL has significant differences in contraction with varying pedalling cadence ($p < 0.05$).

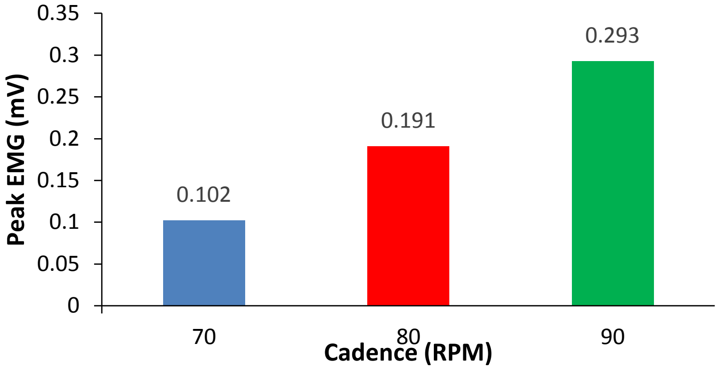

Fig. 2. Comparison of peak EMG of lower extremity muscles with 70 rpm, 80 rpm and 90 rpm

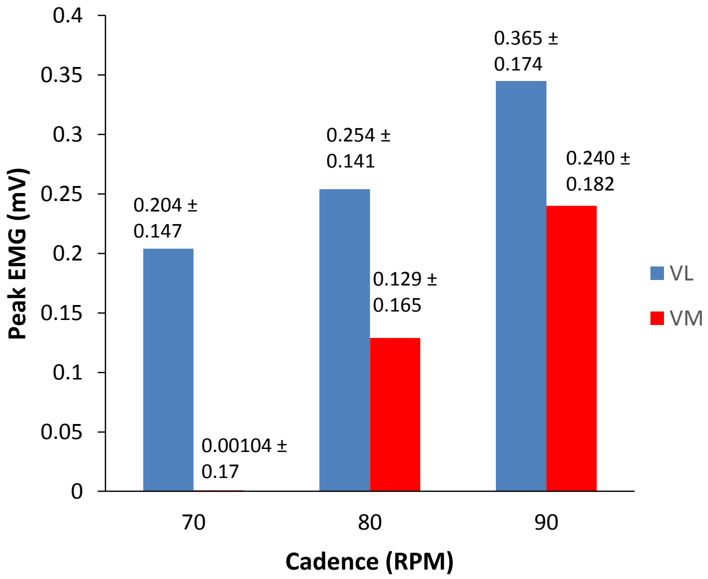

Fig. 3. Comparison of maximum peak EMG on vastus lateralis (VL) and vastus medialis (VM) with 70 rpm, 80 rpm and 90 rpm.

Effect of tilting angle

Unlike the pedalling cadence, tilting angle show non-significantly increasing which only 15.14% higher of muscle activity when all subjects cycling uphill at 30° of tilting angle than 10° (Fig. 4). Fig. 5 explained that there is no significant difference of muscle types during cycling at both tilting angle as no difference sign of slopes, showing parallelism for both separate trends.

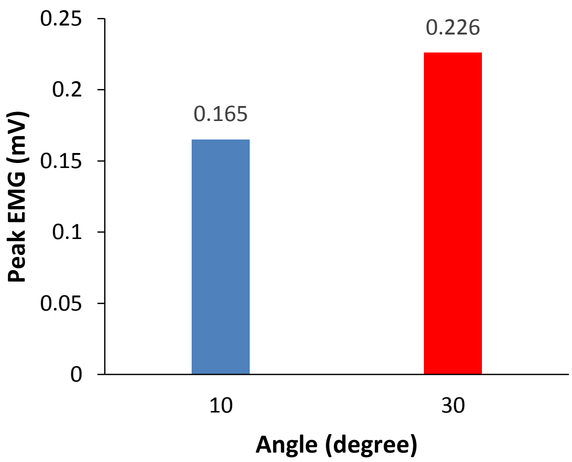

Fig. 4. Comparison of mean peak EMG of lower extremity muscles with 10° and 30° of tilting angle of cycling for all subjects.

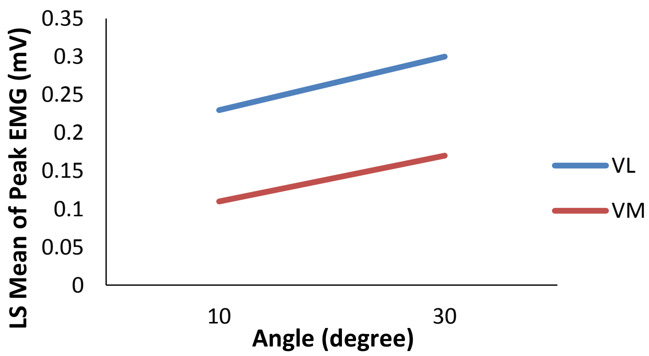

Fig. 5. Representative display of the *Type of muscles vs Tilting angle of cycling* least square means with separate trends for each muscle for all subject.

Effect of gender

Result of mean peak EMG activity across three different pedalling cadences conditions between female and male subjects is represented in Fig. 6. In each pedaling cadence, female showed significantly greater in muscle activity than male. For a tilting angle of cycling, the difference in increase in peak EMG activity is significant for female than male is represented in Fig. 7. Both muscles measured showed a fairly significant interaction effect between gender and type of muscle used. Both genders have slightly downward trend from VL to VM contractions of muscle activity (Fig. 8).

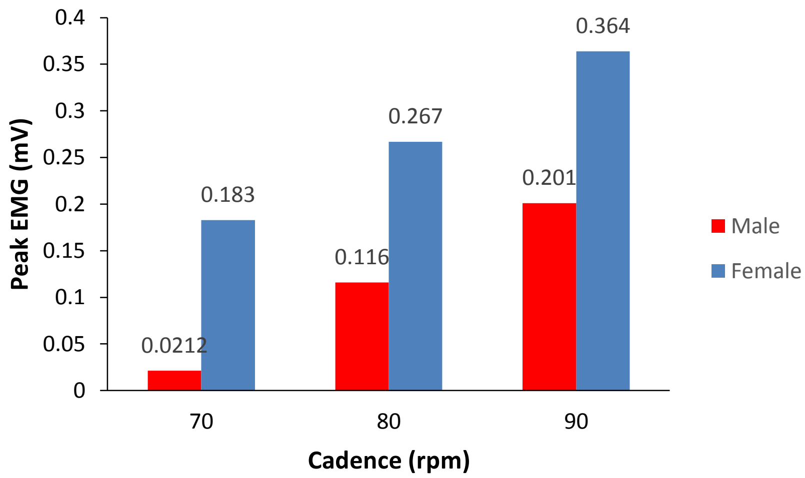

Fig. 6. Comparison of maximum muscle contraction (mean peak EMG) with pedaling cadences of 70 rpm, 80rpm and 90 rpm between female and male subjects.

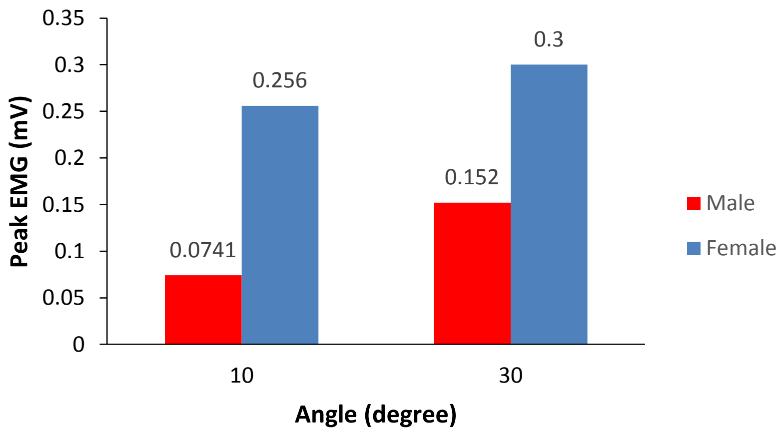

Fig. 7. Comparison of maximum muscle contraction with tilting angle of cycling between female and male subjects

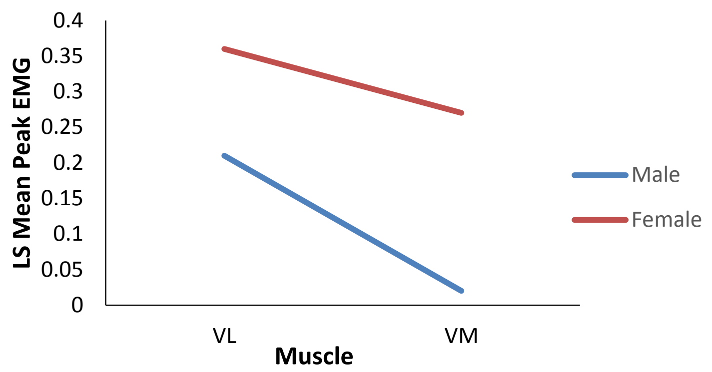

Fig. 6. Representative display of the *Type of muscles vs Genders* least square means with separate trends for female and male subjects

4.0 Discussion

The main finding of the present study is that pedaling cadences influenced mean peak EMG activity for all types of muscle and genders. However, the effect of tilting angles on mean peak EMG activity was not significant.

Hug and Dorel stated that the constraints of pedaling cadence would affect the coordination and contraction of lower extremity muscle as well as muscle recruitment which influence cycling performance [13, 14]. The results of the present study therefore support the idea that during cycling with different pedalling cadence brings significant impact to muscle activity due to higher activation level of muscle. As shown in the result, there is a significant difference of maximum peak EMG across pedalling cadences (compared 70 and 90 rpm). Some findings claimed that a reduction of peripheral muscular and neuromuscular fatigue can be acquired by increasing the pedaling cadence [9, 11, 15-18]. From the results obtained, VL and VM reached the highest maximum contraction during cycling at 90 rpm of pedalling cadence and agreed with the hypotheses of higher pedalling cadence associate with higher muscle activation level. By investigating aspects of individual muscle, VL has produced higher muscle contraction than VM in all three pedalling cadences. A significant difference was found in VL but not VM. It is understood that subjects utilized VL more than VM muscle during cycling. However, to the best of author knowledge, there is no studies compare on muscle activation level between VL and VM. Sather et.al studied that both muscles were more functional during cycling as both are knee-extensors muscle, which produced highest total mechanical works simultaneously [21]. They focused on a comparison among knee-extensors muscles, hip-extensor muscles, hip-flexors, knee flexors muscles and ankle-planar flexor muscle of mechanical works produced [21].

On the other hand, the influence of the tilting angle on muscle activity is insignificant in both muscles during cycling. Although the peak EMG of both muscles was shown higher at 30° than 10° of tilting angle, but this could not proof presence of significant difference in muscle activation during uphill cycling condition in this study. This result was supported by a journal found that three tested slope inclination of 4%, 7% and 10% based on uphill condition did not show any significant changes of muscle activation among the slope in the study [19]. Besides, this result also supported by author Bertucci, who noted that level ground and uphill road cycling produced only minimal differences of crank torque profile when the pedalling at the same cadence [2]. From that, we could observe there is no significant difference of slope or tilt angle on EMG activity. However, some other research done by Clary et. al presented the result of inclination lead some impacts to muscle activation of leg muscle. It was also noted that leg muscle activation increases while varying the inclination from 0 to 12%, but only refer to general leg muscle and not concerned on individual or specific muscles [20]. Based on the reviews, the difference in the environment and equipment in the experiment could influence the muscle activity as the experiment was done during real uphill cycling. In real uphill cycling environment, cyclist overcomes frictional forces acting between tires and ground, and also backward forces developed due to bicycle and cyclist own weight. With steeper inclines, more concentric contractions must be produced to overcome the external force and concentric require more metabolic energy during real uphill cycling. However, in this experiment, subjects used to tilt ergo bicycle in the laboratory. Subjects do not have to overcome all the backward forces since the ergo bicycle is stationary. The propulsive force is only required to exceed the frictional forces developed between the front tire and adjustable belt and also the additional torques (tire's mass moment of inertia multiply the tire's angular acceleration) to start cycling. Furthermore, these frictional forces and torques are almost constant during both tilting angles. Thus, the influence of the tilting angle on muscle activity is very minimal.

For gender effect, female subjects had a higher tendency on contraction of muscle compared to male for all pedalling cadences and tilting angle. From this, females showed convincing significant differences than males in all factors. There is a lack of research investigating the effect of gender effect on muscle activity and performance during cycling. Chiu and Wang found that females showed significantly higher anterior muscle activity, ankle motion, vertical ground reaction force and average heart rate than males [22]. Besides, present result in this study can be supported by other research done by author Malinzak, who concluded that women tend to have less knee flexion angles and greater quadriceps activation and lower hamstring activation in comparison to men during athletic tasks [23]. In addition, the result supported by work done by Zeller, McCrory and Kibler, they stated that eight muscles were tested and demonstrated women had greater muscle activation compared with men. Rectus femoris muscle activation recognized to be statistically greater in women in both are under the linear envelope and maximal activation data [24].

5.0 CONCLUSION

In summary, this is the preliminary study that examined lower extremity muscle activity between genders during uphill cycling by tilting angle of inclination with various pedalling cadence. Some systematic relations were found for interpreting muscle activity. The lower extremity muscle contraction of females is significantly higher than males. Increase in pedalling cadences cause higher EMG activity for lower extremity muscle. Also, muscle activation level of vastus lateralis is significantly higher. The observed of modifications in tilting angle of cycling did not have a significant effect on lower limb muscle activity. Future studies are needed to verify this conjecture.

REFERENCES

[1] J. Srinivasan, V. B., "Effect of LBP on Muscle Activity of Lower Back and Upper Extremity Wile Aerobic Cycling," Intl. Conf. on Biomedical and Pharmaceutical Engineering (2006) 414-417

[2] W. Bertucci, F. Grappe, A. Girard, A. Betik, & J. D. Rouillon, "Effects on the crank torque profile when changing pedalling cadence in level ground and uphill road cycling," Journal of Biomechanics, vol. 38, no. 5 (2005) 1003-1010

[3] L. L. Caldwell, "The Effect of Cycling Cadences on The Coordination of Mono- and Bi-articular Muscles," Biomedical Engineering Conference (pp. 334-337). Amherst, MA: Sixteen Southern Source: IEEE Xplore (1997)

[4] Li, L., Caldwell, G.E. "Muscle coordination in cycling: effect of surface incline and posture," Journal Applied of Physiology Vol. 85 (1998) 927–934

[5] D. J. Sanderson, & A. T. Amoroso, "The influence of seat height on the mechanical function of the triceps surae muscles during steady rate cycling," Journal of Electromyography and Kinesiology: Official Journal of the International Society of Electrophysiological Kinesiology, vol. 19, no. 6 (2009) 465-471
[6] A. R. Chapman, B. Vicenzino, P. Blanch, J. J. Knox, S. Dowlan, & P. W. Hodges,. "The influence of body position on leg kinematics and muscle recruitment during cycling," Journal of Science and Medicine in Sport / Sports Medicine Australia, vol. 11, no. 6, (2008) 519-526
[7] R. P. Patterson, J.L. Pearson, "The influence of flywheel weight and pedalling frequency on the biomechanics and physiological responses to bicycle exercise." Ergonomics, vol. 26, (1983) 659–668
[8] S. A. Kautz, M. E. Feltner, E.F. Coyle, A. M. Baylor. "The pedaling technique of elite endurance cyclists: changes with increasing workload at constant cadence," International Journal of Sport Biomechanics, vol. 7, (1991) 29–53
[9] D. P. Swain, J. P. Wilcox, "Effect of cadence on the economy of uphill cycling," Medicine and Science in Sports and Exercise, vol. 24, (1992) 1123–1127
[10] D. P. Heil, "Scaling of submaximal oxygen uptake with body mass and combined mass during uphill treadmill bicycling," Journal Applied of Physiology, vol. 85, (1998) 1376–1383
[11] E. A. Hansen, L. V. Jorgensen, K. Jensen, B. J. Fregly, G. Sjogaard, "Erratum to: crank inertial load affects freely chosen pedal rate during cycling," Journal of Biomechanics, vol. 35, no. 2, (2002) 277–285, 2002
[12] R. R. Neptune, S. A. Kautz, & M. L. Hull, "The Effect Of Pedaling Rate On Coordination In Cycling," Journal Biomechanics, Vol. 30. No. 10, (1997) 1051 -1058
[13] F. Hug, & S. Dorel, Electromyographic analysis of pedaling," Journal of Electromyography and Kinesiology, vol. 19, (2009) 182–198
[14] C.H. Raymond, K. Joseph, F. Gabriel, Ng. So, & Y.F. Ng, Muscle recruitment pattern in cycling: a review, Physical Therapy in Sport, vol. 6, (2005) 89-96
[15] A. P. Marsh, P. E. Martin, D. J. Sanderson, "Is a joint moment based cost function associated with preferred cycling cadence," Journal of Biomechanics, vol. 33, (2000) 173–180
[16] R. R. Neptune, W. Herzog, "The association between negative muscle work and pedaling rate," Journal of Biomechanics, vol. 32, (1999) 1021–1026
[17] L. McNaughton, D. Thomas, "Effects of differing pedaling speeds on the power-duration relationship of high intensity cycle ergometry," International Journal Sports Medicine, vol. 17, (1996) 287–292
[18] R. P. Patterson, M. I. Moreno, "Bicycle pedaling forces as a function of pedaling rate and power output," Medicine and Science in Sports and Exercise, vol. 22, (1990) 512–516
[19] B. Fonda, & N. Sarabon, "Biomechanics of Cycling," Sport Science Review, Vol. XIX(1-2), (2010) 187-210
[20] J. P. Clarys, K. Alewaeters, & E. Zinzen, "The influence of geographic variations on the muscular activity in selected sports movements," Journal of Electromyography and Kinesiology: Official Journal of the International Society of Electrophysiological Kinesiology, vol. 11, no. 6, (2001) 451-457
[21] B. Sather, "Saddle Height and Musle Activation," CyclingAnalysis.com. (2008)
[22] M.-C. Chiu, & M.-J. Wang, "The effect of gait speed and gender on perceived exertion, muscle activity, joint motion of lower extremity, ground reaction force and heart rate during normal walking," Gait & Posture, Volume 25, Issue 3, (2007) 385–392
[23] R. A. Malinzak, S. M. Colby, D. T. Kirkendallc, & B. A. Yu, "comparison of knee joint motion patterns between men and women in selected athletic tasks," Clinical Biomechanics, Vol. 16, Issue 5, (2001) 438–445
[24] B. L. Zeller, J. L. McCrory, W. B. Kibler, & T. L., "Differences in Kinematics and Electromyographic Activity Between Men and Women during the Single-Legged Squat," The American Journal of Sports Medicine, vol.31, no.3, (2003) 449-456
[25] J. R. Franz, R. K, “How does age affect leg muscle activity/coactivity during uphill and downhill walking,” Gait & Posture, (2013) 378–384
[26] Leg Muscle functions and their recruitment during bicycling [Online]. Available at: http://hubpages.com/hub/Muscles-groups-used-while-cycling,(2013)