Malaysian Journal of Sport Science and Recreation
Vol. 18. No. 2. 310-319, 2022.
DOI: https://doi.org/10.24191/mjssr.v18i2.19582

PREFERRED SADDLE HEIGHTS EFFECTS ON PEDALLING KINEMATICS AMONG SKILLED AND LESS SKILLED CYCLISTS

Hosni Hasan
Nukhairunnisatul Aina Mohd Fadzli
Faculty of Sports Science and Recreation, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia

Sabri Taib
Clever Speda Sdn Bhd, Plaza Perangsang Selangor, Malaysia

Mohd Syrinaz Azli
Defense Fitness Academy, Universiti Pertahanan Nasional Malaysia, Malaysia

Mohd Azim Nural Azhan
Faculty of Sports Science and Recreation, Universiti Teknologi MARA, Cawangan Perlis Kampus Arau, 02600 Arau, Perlis, Malaysia

Received: 13 April, 2022 **Accepted: 22 June, 2022** **Published: 15 Sept, 2022**

Corresponding Authors

***Hosni Hasan,** PhD*
Email: hosnihasan@uitm.edu.my
Faculty of Sports Science and Recreation,
Universiti Teknologi MARA,
40450 Shah Alam, Selangor, Malaysia

PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA

Malaysian Journal of Sport Science and Recreation
Vol. 18. No. 2. 310-319, 2022.
DOI: https://doi.org/10.24191/mjssr.v18i2.19582

PREFERRED SADDLE HEIGHTS EFFECTS ON PEDALLING KINEMATICS AMONG SKILLED AND LESS SKILLED CYCLISTS

Hosni Hasan[1], Nukhairunnisatul Aina Mohd Fadzli[2], Sabri Taib[3], Mohd Syrinaz Azli[4], & Mohd Azim Nural Azhan[5]

[1,2]Faculty of Sports Science and Recreation, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

[3]Clever Speda Sdn Bhd, Plaza Perangsang Selangor, Malaysia

[4]Defense Fitness Academy, Universiti Pertahanan Nasional Malaysia, Malaysia

[5]Faculty of Sports Science and Recreation, Universiti Teknologi MARA, Cawangan Perlis Kampus Arau, 02600 Arau, Perlis, Malaysia

ABSTRACT

The purpose of this study was to compare the movement kinematics between skilled and less skilled cyclists based on their preferred saddle heights. 12 recreational cyclists were recruited for this study, and they were required to perform 10-minute cycling using their own bike (mounted on a bike trainer) which consists of a 4-minute warm-up, and continue with a 6-minute cycle at 90-100 rotations per minute with their preferred saddle height. Reflective markers were placed at the joint involved such as hip, knee, and ankle to assess change in the segment and joint motion parallel to the 90° of the crank cycle (3'o clock) during the study. Additional variables such as cadence and power (watt) were recorded for monitoring purposes. Results showed that there were significant differences ($p<0.05$) in hip and ankle range of motion during pedalling between skilled and less-skilled recreational cyclists. It can be concluded, significantly better range of motion on the hip and ankle performed by the skilled cyclist may be due to suitable saddle height and it might lead to effectiveness on cycling efficiency.

Keywords: *Movement Kinematics, Skilled, Less-skilled, Cyclists, Joint Angle, Pedalling Ki*

PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA

Malaysian Journal of Sport Science and Recreation
Vol. 18. No. 2. 310-319, 2022.
DOI: https://doi.org/10.24191/mjssr.v18i2.19582

INTRODUCTION

Cycling is a sport in which it involves races that runs from only a few seconds to several hours (Moura et al., 2017). According to Gordon (2016) the performance outcome of endurance sports largely dependent on the economy of energy reserve. Changes in different variables can affect the energy requirements of cycling. These variables include: (a) changes in body position, configuration, and orientation; (b) changes in the seat to pedal distance; and (c) the interaction of workload, power output, and pedalling rate. The analysis of the force applied to the pedal is equally important to understand and provide strategies to improve pedalling technique.

Furthermore, in cycling, properly adjusting saddle height was necessary for both injury prevention and optimal performance (Peveler & Green, 2011). The seating position on the bicycle affects cycling movement as reflected in the joint kinematics and therefore the power generating capabilities (Too, 1990; Yoshihuku & Herzog, 1990). Plus, unsuitable saddle height can lead to knee injury or can increase oxygen consumption (Fonda et al., 2014). Most competitive cyclists will even make minor alterations to their equipment to achieve more efficient performance, and the literature presents the basis for these adjustments. Saddle height also influenced pedal stroke due to effectiveness of pedal stroke range of motions will save energy on cycling performance (Hopker et al., 2012).

Besides that, changes in saddle height largely affected knee and ankle joints with greater knee flexion and larger plantar flexion found for higher heights (Bini et al., 2011; Bini, Diefenthaeler, et al., 2014). Indeed, Bini et al. (2010) and Horscroft et al. (2003) showed that power produced by the hip, knee and ankle joints dictated power output during seated cycling and individual joints were sensitive to saddle height effects. Other studies show that the ankle joint was more sensitive rather than the knee joint to changes in pedalling biomechanics (Savelberg et al., 2003). According to Faria and Cavanagh (1978), ranges of motion in cycling found that optimum range of motions for hip, knee, and ankle approximately at 45° for the hip, 75° for the knee, and 20° for the ankle. Furthermore, some educational book has been verified that professional cyclist has better pedalling technique rather than recreational cyclists (Broker, 2003);(Cavanagh, 1986).

In this perspective, pedalling kinematic were important for both skilled and less skilled cyclists to improve pedalling efficiency. Chapman et al. (2009) show that skilled cyclists present less variable ankle motion compared to less skilled cyclists which are less than 1-year experience. Besides, similarities in the configuration of the bicycle component between competitive and recreational road cyclists. Bini, Hume, Lanferdini, et al. (2014) suggest that any differences in joint motions may be determined by long-term adaptation to training. Two-dimensional analyses will be a major approach to assess segmental and joint motion most likely due to larger range of motion in the sagittal plane for hip (42–44°), knee (73–78°), and ankle joints (21–25°) compared to motion at the frontal and transverse planes (Bini et al., 2012; Umberger & Martin, 2001).

PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA

Malaysian Journal of Sport Science and Recreation
Vol. 18. No. 2. 310-319, 2022.
DOI: https://doi.org/10.24191/mjssr.v18i2.19582

According to Bini et al. (2011), previous research suggested that optimal efficiency in cycling may be achieved when the saddle height was set to a knee flexion range of motion of 25° and the pedal crank was at 6 o'clock position. There were no studies that had focus on training cyclists to ride at different saddle heights and measure the differences in performance. Experienced cyclists may adapt to a specific position because of time spent training. Plus, none of the previous studies evaluated pedalling kinematics as an important factor of pedalling technique (Bini et al., 2010). Furthermore, they did not show or compare the bike measurements of the different groups of cyclists, which could affect pedalling kinematics and kinetics (Ferrer-Roca et al., 2012; García-López et al., 2016). Additionally, to the best of our knowledge, limited study reported on the effects of training on pedalling technique, which could be important when comparing cyclists of different competitive levels and with different training volumes. Therefore, this study was conducted to investigate the cycling pedalling kinematics between skilled and less-skilled cyclists with preferred saddle height.

METHODOLOGY

Participants

Twelve cyclists were recruited in this study. Six participants for less skilled cyclists (n= 6; age = 27.17 ± 7.27 years; height = 165.30 ± 5.23 cm; weight = 63.33 ± 10.82 kg) were recreational cyclists and had at least 6 months of cycling experiences with experience of less than 40-kilometre training per day. Six participants for skilled cyclists (n= 6; age = 24.50 ± 8.66 years; height = 169.60 ± 3.93 cm; weight = 66.50 ± 6.53 kg) had a cycling experiences more than 3 years with more than 4 times a week of training. The exclusion and inclusion criteria for skilled and less-skilled participants were based on previous studies on movement kinematics of differing skill level (Jefry et al., 2021). The testing procedures on human participants in this study was approved by Universiti Teknologi MARA Ethical Committee (600-IRMI (5/1/6) REC/509/19).

Procedures

Reflective markers were placed on key anatomical locations of the lower limbs for movement kinematic recording and analysis. The joints involved were hip, knee, and ankle (Bini, Hume, & Kilding, 2014). Special consideration was taken during marker placement to ensure it did not limit the movement of participants. Kinematic data were captured by one video camera (Olympus, Japan) and recorded at 240 frame per second. The video camera was placed at a specific location to record the pedalling technique which was on the right side of the lower limb, perpendicular to the movement plane and 4-meter away from the participants, as shown in Figure 1 (Bini et al., 2012; Ferrer-Roca et al., 2012). All participants used their own bicycle during the testing session, and it was mounted on a smart trainer (Wahoo Kickr, USA).

PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA

Malaysian Journal of Sport Science and Recreation
Vol. 18. No. 2. 310-319, 2022.
DOI: https://doi.org/10.24191/mjssr.v18i2.19582

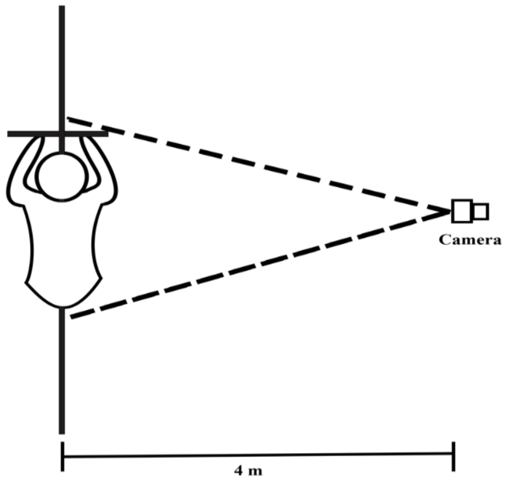

Figure 1: Position of a single camera perpendicular to the movement for 2D motion analysis of cyclists in the sagittal plane.

Participants cycled with their preferred saddle height which was measured from the top centre of the saddle to the paddle spindle with the crank in line with the seat stay range of motion with the horizontal position of the saddle to the bottom bracket (Fonda et al., 2014). Each participant performed a 10-minute dynamic method test including a 4-minute warm-up on the smart trainer and continued with a 6-minute trial at 90-100 rpm by using preferred saddle height (Bini et al., 2012; Ferrer-Roca et al., 2012), and the video was recorded randomly during the 6-minute trial for a duration of 20 seconds. The smart trainer stimulate a real-road riding condition, so the harder the participant pedal, the harder the resistance becomes.

Kinematics data were analysed using an open-source 2D movement analysis software (Kinovea Software version 0.8.15). Kinovea software was found to be a valid (r=0.96) method to measure the variables in this study (García-López & del Blanco, 2017). The hip, knee, and ankle angles were measured at three o'clock (90 degrees), and the mean angle for the 20-second cycle was calculated. In addition, bike computer (Wahoo Element Bold) and sensor cadence (Bryton smart cadence sensor) were used to monitor the cycling performance such as duration of time, cadence, and power output (Watts). This information was measured for monitoring purposes only.

Data Analysis

Data were reported in means and standard deviations for all kinematics variable (hip, knee, and ankle range of motion) for both groups. Independent T-tests (IBMM SPSS Statistics) were conducted to compare the significant differences between skilled and less-skilled cyclists on the kinematic variables. The significant level of all statistical analyses was set at $p<0.05$.

RESULTS

Hip range of motion

The mean of hip range of motion values (Figure 2) on pedalling kinematics between less skilled cyclists was 41.75 ° ± 2.86 ° and skilled cyclists was 34.08 ° ± 2.56°. There was a significant difference ($t = 4.887$, $df = 10$, $p < 0.05$) in hip range of motion values during pedalling kinematics between skilled and less skilled cyclists. The skilled cyclists have a lower hip range of motion compared to the less skilled cyclists.

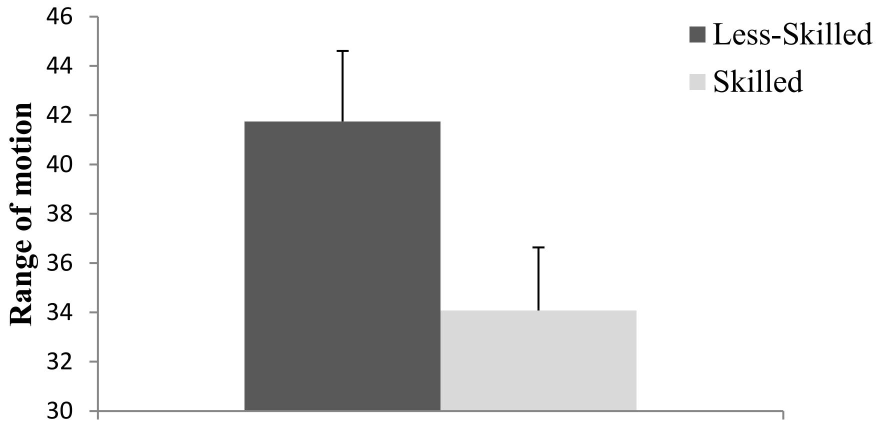

Figure 2: Hip range of motion between skilled and less skilled cyclists.

Knee range of motion

The mean of knee range of motion values (Figure 3) during pedalling between less skilled cyclists was 76.25 ° ± 4.19 °, and for skilled cyclists was 70.37° ± 5.87 °. There were no significant differences ($t = 1.994$, $df = 10$, $p > 0.05$) on knee range of motion between skilled and less skilled cyclists.

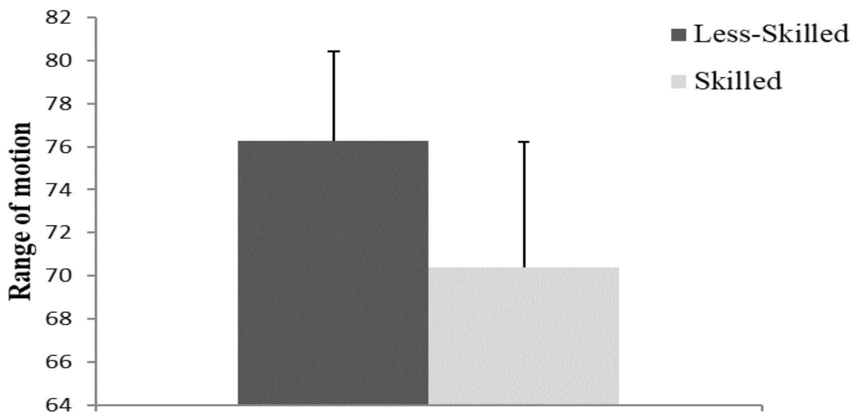

Figure 3: Knee range of motion between skilled and less skilled cyclists

PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA

Ankle range of motion

The mean of ankle range of motion values (Figure 4) on pedalling kinematics between less skilled cyclists was 97.87º ± 11.94º, and for skilled cyclists was 79.16º ± 3.33º. There was a significant difference (t = 3.695, df = 10, p<0.05) on ankle range of motion between skilled and less skilled cyclists. The skilled cyclists have a lower ankle range of motion compared to the less skilled cyclists.

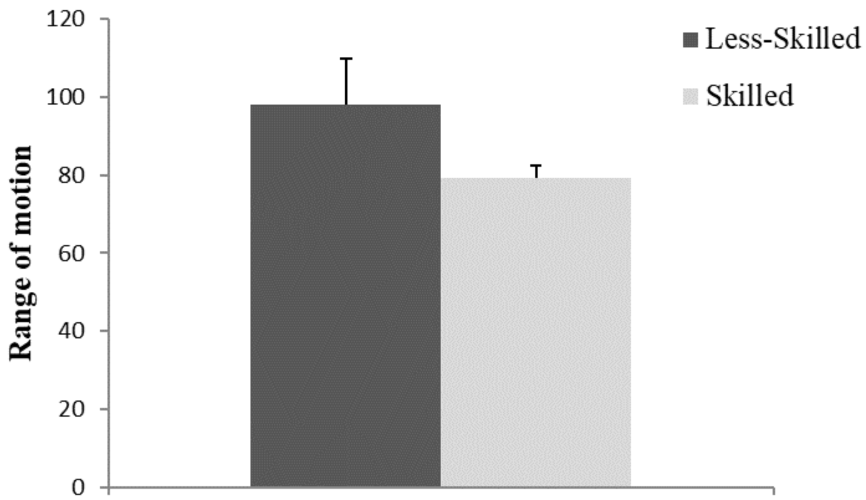

Figure 4: Ankle range of motion between skilled and less skilled cyclists.

Cadence and power

Table 1 showed the mean of average cadence and average power on pedalling movements between skilled and less skilled cyclists. The mean of average cadence on pedalling kinematics for less skilled cyclists was 91.17 ± 6.85, and for skilled cyclists was 91.83 ± 7.14. The mean of average power on pedalling movements for less skilled cyclists was 79.83W ± 7.11W, and for skilled cyclists was 67.33W ± 10.967W.

Table 1: Mean (SD) of average cadence and power watt on pedalling kinematics

Variables	Group	Mean	Standard Deviation
Cadence	Less-skilled	91.17	6.85
	Skilled	91.83	7.14
Power (W)	Less- Skilled	79.83	7.11
	Skilled	67.33	10.97

PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA

Malaysian Journal of Sport Science and Recreation
Vol. 18. No. 2. 310-319, 2022.
DOI: https://doi.org/10.24191/mjssr.v18i2.19582

DISCUSSIONS

This study determined the comparison of pedalling kinematics between skilled and less skilled cyclists with their preferred saddle height. In bicycle outlets, cycling clinics and research related to cycling, bike fitting takes into a justification of lower limb joint range of motions determined from a static position of cyclists at the six o'clock crank position to measured. As we know that cycling is a dynamic movement, so bike fitting should ideally be based on dynamic assessment looking at the average of consecutive pedal revolutions. Given the truth that the static six o'clock crank range of motion approach was often utilized in bicycle retailers and clinics, the results of the previous study showed that the three o'clock position would be a better method to set up a cyclist on a bicycle if dynamic cycling range of motion were not available (Bini & Hume, 2016). The measurement of joint range of motions with their bicycles has the potential to enhance the existing techniques for bicycle configuration components optimization. Plus, joint range of motion were important variables for the configuration of bicycle components that help to reduce injury risk and optimize the performance (Bini et al., 2011; Peveler & Green, 2011), but the assessment of joint range of motions of cyclists may depend on the type of exercise and conditions.

Lower body was the main focus in motion analysis of cyclists due to their large contribution to crank power production via the action of lower limb muscles. It has been found when cyclists were instructed to perform cyclic motion by using a smart trainer that enables the researcher to track joint and segment to investigate their lower limb kinematics which was hip, knee and ankle. There were significant differences in the lower limb kinematics between skilled and less skilled cyclists hip joint, as the result shown in figure 2, skilled cyclist has a lower hip range of motion which was 34.08 º ± 2.56º compared to less skilled cyclist which was 41.75 º ± 2.86 º. There were several possible explanations for this result. The hip flexor muscle strength may have been responsible for these changes because stronger hip flexor muscle will allow better control and can produce more power with less movement. The hip flexor muscle was also one of the muscle responsible for the lifting motion of the leg during the upstroke phase (Esmaeili & Maleki, 2020). Moreover, a stronger hip flexor helps to improve the transition around the top dead centre and delays fatigue, resulting in a more precise movement and greater cadence control. Due to the control in cadence, the cyclists did not reach maximal workload level to ascertain different joint of motion. Greater hip angle in cycling may also increase the risk of injury. Study had shown that greater hip adduction might lead to anterior knee pain (Bailey et al., 2003), and an extreme pelvis lateral inclination was related to low back pain.

Based on a previous study done by Gatti et al. (2021) It has been discovered that hip and ankle kinematics were the most important predictors of knee joint loading. Although there were no significant differences in the knee angle between less skilled and skilled cyclist but the main predictor for knee joint loading were the hip and ankle kinematics. Abnormal knee joint loading has been shown to be a mechanism of injury including anterior cruciate ligament (Czasche et al., 2018). This study showed in figure 3 the knee range of motion received a less difference between skilled cyclists which was 70.37 ± 5.87 and the less skilled cyclists were 76.25 ± 4.19 due to the larger range of motion of the joint. Both categories match the optimum knee range of motion which in the range of 60°- 80° (Folland & Morris, 2008).

PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA

Pedalling kinematics was evaluated as an important factor of pedalling techniques (García-López et al., 2016). Based on the present study, it's observed that skilled cyclist have a better understanding of the proper saddle height to be used maybe because of their experience and knowledge. It also the main concern of bicycle shop to adjust the saddle height before the cyclists begin cycling as this might cause discomfort and lower back pain if the ride was more than an hour. The skilled cyclists had experience in the long term of training so they already adapt to the movement. Moreover, to reduce muscle fatigue after prolonged training, the cyclists need to decrease the activity of the major leg extensor muscles during downstroke which involved rectus femoris and vastus lateralis as knee extensor and increasing the activity of the major leg flexor muscles during the upstroke.

Next, the ankle range of motion was measured from the ankle to the front of the pedal and parallel to the 90° of the crank cycle (3'o clock) during pedalling. According to Chapman et al. (2009), a greater range of motion for the ankle range of motion was observed in less skilled cyclists compare to the skilled cyclists, which was a similar result as this study. Ankle range of motion on pedalling kinematics showed there were significant differences of p-value lesser than 0.05, (p-value =0.04), with the mean of the ankle range of motion on pedalling kinematics for less skilled cyclists was 97.87 ±11.94 while skilled cyclists were 79.16 ± 3.33 (Figure 4). Increases in pedalling cadence led to smaller ranges of motion for the ankle joint, which were associated with an effort to sustain ankle stiffness and to improve ankle plantar flexors action as a force transfer link to the cranks (Sanderson et al., 2006). Plus, fatigue also could lead to increases in ankle range of motion (Bini et al., 2010) due to maintaining within the range of cadence. Other studies showed that the ankle joint was more sensitive than the knee joint to changes in pedalling biomechanics (García-López et al., 2016). These results suggest that the ankle joint plays a role in cycling performance due to its function as a connection to the lower limbs and the pedal.

The purpose of why saddle height was the main of bike fitting because mechanical work at individual joints might be a balance among the hip, knee and ankle joints. Skilled nor less skilled cyclist, need to find the suitable saddle height which can improve their cycling kinematics and reduce injuries. It has been shown that low saddle height resulted in increased knee adduction moments with longer duration and may lead to patellofemoral pain syndrome (Wang et al., 2020). The optimum pedalling rhythm was one that sustains the minimum pedalling force required to deliver bike power.

Increasing pedalling cadence for persistent workload may possibly lead to lower muscle activation. In common, road cyclist pedalling cruising speed optimum for a cadence of 90-100 rpm for varying reasons, such as to reduce pedal force per crank and to allied changes in muscle action. Skilled cyclists have slightly increased in an average cadence which was 91.83 ± 7.139 rather than less skilled cyclists were 91.17 ± 6.853. Skilled cyclists might have a specific individual pedalling technique due to high training volume and could induce pedalling technique adaptation that would likely harm their physiological response. Plus, they allow using slow-twitch muscle fibers for major muscle power and allow the anaerobic capability to be reserved to delay from fatigue (Kido et al., 2013).

PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA

CONCLUSION

In summary, joint kinematics has grown in popularity as a bike fitting method, and it may be used to analyse cyclists of all abilities. The dynamic analysis of bike configuration can provide meaningful information on pedalling technique and skills. Modifications in pedalling cadence, body position on the bicycle, power output and fatigue have a larger impact on lower limb joint range of motions.

This study has concluded that there were significant differences in hip and ankle range of motion between skilled and less skilled cyclist based on their preferred saddle height. Less skilled cyclist was more likely to sustain injuries if their bikes were not properly fitted. An interesting issue for future studies would be to require the researcher to set the suitable preferred saddle height for the participants to cycle in a relaxed position. Plus, a comparison of motion from cyclists of different disciplines such as road and mountain bikes should be conducted to provide normative data for bicycle configuration.

Author's contribution

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; (c) approval of the final version and (d) agree to be accountable for all aspect. All authors meet the above criteria.

Conflict of Interest

The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

REFERENCES

Bailey, M., Maillarder, F., & Messenger, N. (2003). Kinematics of cycling in relation to anterior knee pain and patellar tendinitis. *Journal of sports sciences*, *21*(8), 649-657.

Bini, R., Hume, P. A., & Croft, J. L. (2011). Effects of bicycle saddle height on knee injury risk and cycling performance. *Sports medicine*, *41*(6), 463-476.

Bini, R. R., Diefenthaeler, F., & Carpes, F. P. (2014). Determining force and power in cycling: A review of methods and instruments for pedal force and crank torque measurements. *International SportMed Journal*, *15*(1), 96-112.

Bini, R. R., Diefenthaeler, F., & Mota, C. B. (2010). Fatigue effects on the coordinative pattern during cycling: Kinetics and kinematics evaluation. *Journal of Electromyography and Kinesiology*, *20*(1), 102-107.

Bini, R. R., & Hume, P. (2016). A comparison of static and dynamic measures of lower limb joint angles in cycling: Application to bicycle fitting. *Human Movement*, *17*(1), 36-42.

Bini, R. R., Hume, P. A., & Kilding, A. E. (2014). Saddle height effects on pedal forces, joint mechanical work and kinematics of cyclists and triathletes. *European journal of sport science*, *14*(1), 44-52.

Bini, R. R., Hume, P. A., Lanferdini, F. J., & Vaz, M. A. (2014). Effects of body positions on the saddle on pedalling technique for cyclists and triathletes. *European journal of sport science*, *14*(sup1), S413-S420.

Bini, R. R., Senger, D., Lanferdini, F., & Lopes, A. L. (2012). Joint kinematics assessment during cycling incremental test to exhaustion. *Isokinetics and Exercise Science*, *20*(2), 99-105.

Broker, J. (2003). Cycling biomechanics: road and mountain. *High Tech Cycling. Champaign, IL: Human Kinetics*, 147-175.

Cavanagh, P. R. (1986). The biomechanics of cycling studies of the pedalling mechanics of elite pursuit rider. *Science of cycling, Human Kinetics*.

Chapman, A., Vicenzino, B., Blanch, P., & Hodges, P. (2009). Do differences in muscle recruitment between novice and elite cyclists reflect different movement patterns or less skilled muscle recruitment? *Journal of Science and Medicine in Sport*, *12*(1), 31-34.

Czasche, M. B., Goodwin, J. E., Bull, A. M., & Cleather, D. J. (2018). Effects of an 8-week strength training intervention on tibiofemoral joint loading during landing: a cohort study. *BMJ open sport & exercise medicine*, *4*(1), e000273.

Esmaeili, J., & Maleki, A. (2020). Muscle coordination analysis by time-varying muscle synergy extraction during cycling across various mechanical conditions. *Biocybernetics and Biomedical Engineering*, *40*(1), 90-99.

Faria, I., & Cavanagh, P. R. (1978). *The physiology and biomechanics of cycling*. John Wiley & Sons.

Ferrer-Roca, V., Roig, A., Galilea, P., & García-López, J. (2012). Influence of saddle height on lower limb kinematics in well-trained cyclists: static vs. dynamic evaluation in bike fitting. *The Journal of Strength & Conditioning Research*, *26*(11), 3025-3029.

Folland, J., & Morris, B. (2008). Variable-cam resistance training machines: Do they match the angle–torque relationship in humans? *Journal of sports sciences*, *26*(2), 163-169.

Fonda, B., Sarabon, N., & Li, F.-X. (2014). Validity and reliability of different kinematics methods used for bike fitting. *Journal of sports sciences*, *32*(10), 940-946.

PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA

García-López, J., & del Blanco, P. A. (2017). Kinematic analysis of bicycle pedalling using 2d and 3d motion capture systems. *ISBS Proceedings Archive*, *35*(1), 125.

García-López, J., Díez-Leal, S., Ogueta-Alday, A., Larrazabal, J., & Rodríguez-Marroyo, J. A. (2016). Differences in pedalling technique between road cyclists of different competitive levels. *Journal of sports sciences*, *34*(17), 1619-1626.

Gatti, A. A., Keir, P. J., Noseworthy, M. D., Beauchamp, M. K., & Maly, M. R. (2021). Hip and ankle kinematics are the most important predictors of knee joint loading during bicycling. *Journal of Science and Medicine in Sport*, *24*(1), 98-104.

Gordon, B. (2016). *Effects of structural foot support on lower limb kinematics and electromyography during cycling*. California State University, Fullerton.

Hopker, J., Coleman, D., Jobson, S. A., & Passfield, L. (2012). Inverse relationship between V O2max and gross efficiency. *International journal of sports medicine*, *33*(10), 789-794.

Horscroft, R. D., Davidson, C. J., McDaniel, J., Wagner, B. M., & Martin, J. C. (2003). Effects of saddle height on joint power distribution. *Medicine & Science in Sports & Exercise*, *35*(5), S16.

Jefry, M. H. M., Hasan, H., Azidin, R. M. F. R., & Azhan, M. A. N. (2021). Correlation Analysis on the Effects of Wearing Compression Socks and Smooth Socks on Running Kinematics among Runners. *Environment-Behaviour Proceedings Journal*, *6*(SI4 (Special Issue 4)).

Kido, S., Nakajima, Y., Miyasaka, T., Maeda, Y., Tanaka, T., Yu, W., Maruoka, H., & Takayanagi, K. (2013). Effects of combined training with breathing resistance and sustained physical exertion to improve endurance capacity and respiratory muscle function in healthy young adults. *Journal of physical therapy science*, *25*(5), 605-610.

Moura, B. M. d., Moro, V. L., Rossato, M., Lucas, R. D. d., & Diefenthaeler, F. (2017). Effects of saddle height on performance and muscular activity during the Wingate test. *Journal of Physical Education*, *28*.

Peveler, W. W., & Green, J. M. (2011). Effects of saddle height on economy and anaerobic power in well-trained cyclists. *The Journal of Strength & Conditioning Research*, *25*(3), 629-633.

Sanderson, D. J., Martin, P., Honeyman, G., & Keefer, J. (2006). Gastrocnemius and soleus muscle length, velocity, and EMG responses to changes in pedalling cadence. *Journal of Electromyography and Kinesiology*, *16*(6), 642-649.

Savelberg, H. H., Van de Port, I. G., & Willems, P. J. (2003). Body configuration in cycling affects muscle recruitment and movement pattern. *Journal of applied biomechanics*, *19*(4), 310-324.

Too, D. (1990). Biomechanics of cycling and factors affecting performance. *Sports medicine*, *10*(5), 286-302.

Umberger, B. R., & Martin, P. E. (2001). Testing the planar assumption during ergometer cycling. *Journal of applied biomechanics*, *17*(1), 55-62.

Wang, Y., Liang, L., Wang, D., Tang, Y., Wu, X., Li, L., & Liu, Y. (2020). Cycling with low saddle height is related to increased knee adduction moments in healthy recreational cyclists. *European journal of sport science*, *20*(4), 461-467.

Yoshihuku, Y., & Herzog, W. (1990). Optimal design parameters of the bicycle-rider system for maximal muscle power output. *Journal of biomechanics*, *23*(10), 1069-1079.