The Effect of Saddle Position on Maximal Power Output and Moment Generating Capacity of Lower Limb Muscles During Isokinetic Cycling

Jeroen Vrints, Erwin Koninckx, Marc Van Leemputte, and Ilse Jonkers

Saddle position affects mechanical variables during submaximal cycling, but little is known about its effect on mechanical performance during maximal cycling. Therefore, this study relates saddle position to experimentally obtained maximal power output and theoretically calculated moment generating capacity of hip, knee and ankle muscles during isokinetic cycling. Ten subjects performed maximal cycling efforts (5 s at 100 rpm) at different saddle positions varying ± 2 cm around the in literature suggested optimal saddle position (109% of inner leg length), during which crank torque and maximal power output were determined. In a subgroup of 5 subjects, lower limb kinematics were additionally recorded during submaximal cycling at the different saddle positions. A decrease in maximal power output was found for lower saddle positions. Recorded changes in knee kinematics resulted in a decrease in moment generating capacity of biceps femoris, rectus femoris and vastus intermedius at the knee. No differences in muscle moment generating capacity were found at hip and ankle. Based on these results we conclude that lower saddle positions are less optimal to generate maximal power output, as it mainly affects knee joint kinematics, compromising mechanical performance of major muscle groups acting at the knee.

Keywords: saddle height, maximal performance, musculoskeletal modeling
determining pedaling cadence in short term maximal cycling (Van Soest and Casius, 2000) and it was found that apart from Hill’s power-velocity relationship activation dynamics have a large contribution in determining optimal pedaling rate.

This study describes the effect of saddle position on the maximal power output during short maximal cycling efforts. Using recorded lower limb kinematics and musculoskeletal modeling, the moment generating capacity of the major lower limb muscles (m. gluteus maximus (GMax), m. biceps femoris (BF), m. rectus femoris (RF), m. vastus intermedius (VI), m. Gastrocnemius (GAS), m. soleus (SOL) and m. tibialis anterior (TA)) was compared for the different seating positions. We hypothesize a reduced maximal power output due to the reduction in the maximal moment generating capacity of the major lower limb muscles as the seating position is mechanically less favorable as it shifts muscle lengths and moment arms away from their optimal values.

Methods

Subjects

Ten trained males (age: 23.4 ± 6.6 years; body mass: 70.3 ± 6.8 kg; height: 177.1 ± 6.3 cm) participated in this study. All participants had a minimum of 2 years experience in cycling and had an average training background of 8.2 ± 2.7 hr per week. Participants were fully informed on the procedures of the study and agreed to participate by signing the informed consent. The Local Ethics Committee approved the methods used in this study.

Study protocol

All tests were performed using the participant’s personal racing bike, which was mounted on a custom-made isokinetic ergometer (Koninckx et al., 2008). The latter allows us to impose a preset motor-controlled cadence. Maximal power output was determined after a 10-min warming-up (100 W at 100 rpm). Participants performed a 5-s maximal isokinetic cycling effort in a seated position at 100 rpm in six different saddle positions: ‘109%’-position’ (109% of inner leg length—taken as a reference position for all participants), High position (‘109% +2 cm’), High and Forward (‘109% +2 cm and 0.6 cm forward’), Low position (‘109% –2 cm’), Low and Backward (‘109% –2 cm and 0.6 cm backward’) (see Figure 1). Hereby, inner leg length was defined as the distance from os pubis to the ground and saddle position was measured from the center of the pedal spindle to the saddle, with the crank in the direction of the seat tube. The forward/backward movement of the saddle for the low and high position accounted for the extra offset of the saddle with respect to the crank and pedal axis due to the seat tube angle. This forward/backward movement therefore slightly corrected the seat tube angle. A 7-min adaptation period (100 W at 100 rpm) after changing the saddle position and a 10-min cooling-down period after the test was performed by the participants. During the kinematic data collection, a subgroup of 5 participants performed a second test in which they cycled, after a 10-min warming-up (100 W at 100 rpm), at 3 W/kg body weight and 100 rpm during one minute at the different-saddle positions. A 7-min adaptation period was given between changes in saddle position.

Materials and Data Analysis

Maximal Power Output. Crank torque (N·m) was measured continuously (1 kHz) during the maximal cycling efforts. Incomplete revolutions at the start and at the end of each effort were omitted from the analyses. The mean torque (N·m) per full revolution was multiplied by cadence to obtain mean power output per revolution. Mean maximal power output was calculated based on the revolutions yielding a mean power output of at least 95% of the highest power per revolution.

Kinematics

Kinematic data were measured at 100 Hz using a Krypton 3D motion measurement system (Metris, Leuven, Belgium). Infrared-emitting diode clusters (LEDs) were
Effects of Saddle Position in Isokinetic Cycling

attached to the pelvis, thigh and shank, whereas anatomical LEDs were placed on the right toe, heel, lateral foot ankle and spina iliaca superior anterior (ASIS). The position of the LED cluster was calibrated to the leg anatomy by referring to anatomical landmarks (most prominent aspect of the lateral and medial malleolus, most prominent aspect of lateral and medial epicondylos, right and left ASIS). Kinematic data were recorded during the last 10 s of the 1-min cycling bout of the second test. To allow synchronization of kinematics and torque measurements with the crank angle, crank arm position was monitored using a switch detector.

Inverse kinematics were performed in OpenSim (Simbios, Stanford, USA). A generic musculoskeletal model based on Delp et al. (1990) was defined consisting of 7 segments (right leg and pelvis) and containing 11 degrees of freedom. The degrees of freedom in the model are (1) six DOF defining the translation and rotation of pelvis with respect to ground—pelvis tx, ty, tz and pelvis_tilt, these DOFs were not further analyzed in this paper, (2) three DOF defining the rotation between pelvis and thigh: hip flexion/extension, hip ab/adduction, hip exo/endorotation, (3) one DOF defining the rotation between femur and tibia: knee flexion/extension and (4) one DOF defining the rotation between tibia and foot: ankle plantar/dorsal flexion. The generic musculoskeletal model was linearly scaled for each participant using the marker positions collected during the static calibration. The individual segments were isotropically scaled based on an optimal fit between experimentally recorded marker positions on the test subject and defined markers positions in the musculoskeletal model. Hereafter, kinematics of pelvis, hip, knee and ankle were calculated using an inverse kinematics procedure. This procedure minimizes at each time instance the distance between the measured marker coordinates of all technical and anatomical markers on the individual segments and their corresponding marker locations in the segment axis frame of the scaled musculoskeletal model by adjusting the generalized coordinates of the relevant degrees of freedom. The average hip, knee and ankle angle profiles were calculated over the entire cycle for the different saddle positions (for definition of hip, knee and ankle angle, see Figure 2) and included for further analysis.

Moment Generating Capacity

The musculoskeletal model contains a definition of the muscle geometry. Each muscle is represented as a line actuator with defined origin and insertion, therefore determining its moment arm with respect to the joint’s degree of freedom. Furthermore, actuator specific muscle-tendon parameters are defined to allow the calculation of muscle force depending on muscle length using a Hill muscle model (Zajac, 1989). In the model, twenty muscle-tendon actuators are included, yet in the further analysis only those with a main function in the sagittal plane will be further discussed: m. gluteus maximus (GMax), m. biceps femoris (BF), m. rectus femoris (RF), m. vastus intermedius (VI), m. Gastrocnemius (GAS), m. soleus (SOL) and m. tibialis anterior (TA). Using the Hill muscle model (Zajac, 1989) and based on the kinematics trajectory at the relevant joints, muscle-tendon length and consequent force generating capacity of individual muscles was calculated. Taking into account the individual moment arm at the relevant joints, the moment generating capacity of the muscle throughout the cycle was calculated for the different saddle positions. For each muscle, the average moment generating capacity was calculated for the sections of the pedal cycle for which muscle activity is described in literature (Dorel et al., 2008; Hug and Dorel, 2009; Jorge and Hull, 1986).

Statistics

Differences in short term maximal power output, kinematics and moment generating capacity were tested using a one-way repeated-measures analysis of variance in Statistica 8.0 (Statsoft, Tulsa, USA). In this test, saddle position was considered as an independent within-subject factor. For pairwise comparison of two saddle positions, Tukey’s HSD approach was used as a post hoc test. Statistical significance was set at $p < .05$. 

Figure 2 — Conventions used to specify joint angles. (1) hip flexion/extension: angle between long axis of pelvis and thigh segment; (2) knee flexion/extension: angle between long axis of thigh and shank segment; (3) ankle dorsi/plantar flexion (angle between the shank and long axis of the foot).
Results

The lowest maximal power output values were found for the lowest saddle positions, with significant differences with all other positions. There was no difference between the highest positions or between the highest and 109%-position (see Figure 3). Accounting for the seat tube angle at both high and low positions, this did not affect the maximal power output.

In the kinematics, there was a tendency, yet not statistically confirmed, for more hip flexion at the lower positions during the entire crank cycle (see Figure 4). The same was found for the knee, with more knee flexion during the entire cycle between the low and the other saddle positions (see Figure 4). No significant differences were found between the two high positions or the two low positions, so changing seat tube angle did not reveal a significant effect. For the ankle joint, there was a trend to more plantar flexion with the pedal at the lowest point in the crank cycle for the high positions and more dorsal flexion at the beginning of the cycle for the lowest positions (see Figure 4).

The moment generating capacity of the muscles with a function at the hip, showed reduced moment generating capacity in the active period of the muscle for the lower positions compared with the other positions, yet these differences were not confirmed statistically. For the knee joint, the lowest moment generating capacity was found for different muscles functioning at the knee in the lowest saddle positions. The lowest saddle positions induced a decrease in moment generating capacity of BF and RF, with a significant difference between the lowest positions and position ‘High and Forward’ (p < .05) (see Figure 5). For the VI, the highest moment generating capacity was found for position ‘High and Forward’ (see Figure 5). Significant differences were observed between the lowest positions and positions 109% and ‘High’ (p < .05) and between the lowest positions and ‘High and Forward’ (p < .01). As for the hip joint, no differences were statistically confirmed at the ankle joint in muscle moment generating capacity between the different saddle positions.

Discussion

In this study, we show that saddle position affects maximal power output. Furthermore, we indicate that the associated changes in lower limb kinematics affect the maximal moment generating capacity of the most important lower limb muscles.

At a lower saddle position, maximal power output during a short maximal cycling effort at 100 rpm is reduced. There are no differences in maximal power output between the high saddle positions and the 109% saddle position. This finding conflicts somewhat with previous submaximal cycling studies that report decreased efficiency for both lower and higher saddle positions. However, these studies report oxygen uptake required to cycle at a constant power output as outcome measure (Nordeen-Snyder, 1977; Shennum and deVries, 1976). This contrasts with the short maximal cycling efforts studied in this study that are merely alactatic and therefore more dependent on biomechanical than physiological parameters.

Figure 3 — Maximal power output for a short maximal cycling effort at 100 rpm at different saddle positions. **p < .01; ***p < .001.
We studied the effect of saddle height on lower limb kinematics using 3D motion capture measurements. The only difference in lower limb kinematics is an increased knee flexion and reduction of knee extension with decreasing saddle height. A trend, yet not statistically confirmed is shown for hip and ankle joints to change in the same direction. These major adaptations to changing saddle height to occur at the knee are previously found by Nordeen-Snyder (1977) and Price and Donne (1997).

The observed changes in maximal power output are related to the changes in moment generating capacity of specific lower limb muscles as observed in our musculoskeletal modeling study. Using experimentally measured kinematics at different saddle heights, a musculoskeletal model scaled to the subject’s anthropometry is used to calculate the effect of saddle height on the moment generating capacity of the lower limb muscles. The changes in the moment generating capacity therefore directly reflect the combined effect of the changes in the muscle-tendon length and moment arm length. Using this approach, we assume that the differences in kinematics between maximal and submaximal cycling are minimal as the contact points within the bicycle-rider setup are not changed. Given this assumption, the changes in the lower limb kinematics associated with changes in saddle position mainly affect the muscle moment generating capacity at the knee for biceps femoris, rectus femoris and vastus intermedius, with no significant differences found in moment generating capacity at the hip and ankle joint. The lowest moment generating capacity at the knee joint is found for biceps femoris, rectus femoris and vastus intermedius. A similar trend is shown at the hip. The lowest saddle positions, independent of forward or backward movement of the saddle, are therefore less optimal. This is confirmed experimentally in the reduction of the maximal power output as well as mathematically in the reduction of the calculated moment-generating capacity at the knee joint. The highest moment generating capacity at the knee joint is associated with the highest saddle positions in the test subjects.

**Figure 4** — Average kinematics (± SEM for 109% position) for hip, knee and ankle in function of the pedal cycle for different saddle positions in the test subjects. SEM values were similar to the values of the 109% position for the other positions. TDC: Top Dead Center; BDC: Bottom Dead Center. Key: ———— 109%; – – – – High and Forward; — — — High; - - - - Low and Backward; — — Low.
capacity at the knee joint found for the ‘High and Forward’ saddle positions is not directly reflected in an increase in power output. The highest maximal power output resulted from the 109% position. These findings seem to suggest that power output depends not only on the muscular moment generating capacity at the knee joint, which only reflects a theoretical maximum. The ability of the cyclist to appropriately use this mechanical advantage may be hindered as his coordination pattern will not allow preferential activation of these muscle groups (BF, vasti, RF). Especially for high cadences, the cyclist’s ability to control muscle coordination accordingly may be a more prominent hindering factor. Future research, should therefore consider the effect of altered cadence on moment generating capacity as well as maximal power output.

In this study, the effect of saddle position on moment generating capacity of individual muscles at the different joints of the lower limb is discussed. The significant differences in moment generating capacity between different saddle positions are found at the knee joint. This is particularly important as the knee is, together with the hip, the joint with the greatest relative contribution to the total net moment during cycling (Ericson et al., 1986a,b,c; Bini et al., 2008; Martin and Brown, 2009; Mornieux et

**Figure 5** — Muscle moment generating capacity (± SEM) at the knee for biceps femoris, rectus femoris and vastus intermedius. Positive values indicate knee-extension moment. Negative values indicate knee flexion moment. * p < .05.
al., 2007) and knee extensors and hip extensors are the main relative energy producers during submaximal and maximal cycling (Martin and Brown, 2009). It should be stressed that our results relate to the theoretical maximal moment generating capacity of the muscle and do not allow an extrapolation to the effect of saddle height on the individual joint moments at the hip and knee as well as the muscle force distribution during cycling. This analysis would require the extension of the measurement protocol with pedal forces and EMG measurements. Nevertheless, our findings that the moment generating capacity at the knee is affected by saddle height suggest that a major change in total net moment is to be expected given the relative importance of the knee.

From this study, that combines experimentally measures of power output, lower limb kinematics and musculoskeletal modeling, it could be concluded that lower saddle positions are less optimal to generate maximal power output, as it alters the lower limb kinematics so that the mechanical performance of the major muscle groups acting at the knee, decreases.

References


