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Analysis of pedaling motion focusing on the crank angle corresponding to the maximum pedal angle

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1. Introduction

The measurement of joint angle using motion capture is common for the analysis of pedaling motion. Previous studies (Fukuda et al. 2018) have understood the state of muscle activity in which force is exerted by determining changes in joint moments. The authors have been conducting research focusing on the pedal angle rather than the ankle joint angle, considering that pedaling is efficient, in which the extension muscles of the hip joint and knee joint cooperate during pedaling. The purpose of this study was to analyze the effect of joint angle change on the cooperating relationship from the pedal angle.

2. Materials and Methods

Twenty-four male amateur riders (age 39.2 ± 7.1 y, height 171.8 ± 4.6 cm, weight 65.9 ± 6.4 kg) participated. Each rider's bicycle was attached to a bicycle trainer (Power Beam Pro, CycleOps), and the load was calculated by multiplying their weight with their power-to-weight ratio (which corresponded to approximately 1.5 to 3.0). The riders pedaled at their calculated load, and pedaling data for 25 s were captured using a motion capture (MC) system (GE60/W, Library). The MC was used to measure the coordinates of six points of both legs during pedaling (acromion, greater trochanter, knee joint, ankle joint, fifth metatarsal head, and pedal axis). A coordinate space was determined in the vertical direction, crankshaft direction, and longitudinal direction by using both markers outside the pedal shaft, and the coordinates of each marker were obtained. From the coordinates projected on the sagittal plane, the joint angles of the hip, knee, and ankle joints were determined. Further, the pedal angle with the horizontal plane and the crank angle with the left foot upper dead center at 0° were determined. Thereafter, the joint angle and the pedal angle for each crank angle value were averaged for 25 s. The analysis was performed using the joint angles and pedal angles (total of 192 data in both legs).

3. Results and Discussion

First, let θKmin and θHmin be the crank angles at which the extension waveforms of the knee and hip joints have their minimum values. In addition, the difference between these angles, θHmin − θKmin, is calculated as the hip and knee joint index (knee hip joints interlocking index, KHII). Fig. 1, with θKmin and θHmin as the horizontal axis and KHII as the vertical axis, shows that the knee joint starts to extend a small amount before passing the top dead center (TDC) (−30 to −10°), and hip joint starts to extend immediately after passing the TDC (5° ~ 25°). In addition, because the hip and knee joints move in conjunction with each other as the start of extension approaches the TDC (0°) in both cases, a smaller KHII value corresponds with higher coordination, and the hip and knee joints are considered to move in coordination. Because the leg movement associated with crank rotation is determined by the angle of the ankle joint, the movement of the knee and hip joints when passing the TDC is also determined by the ankle joint movement.

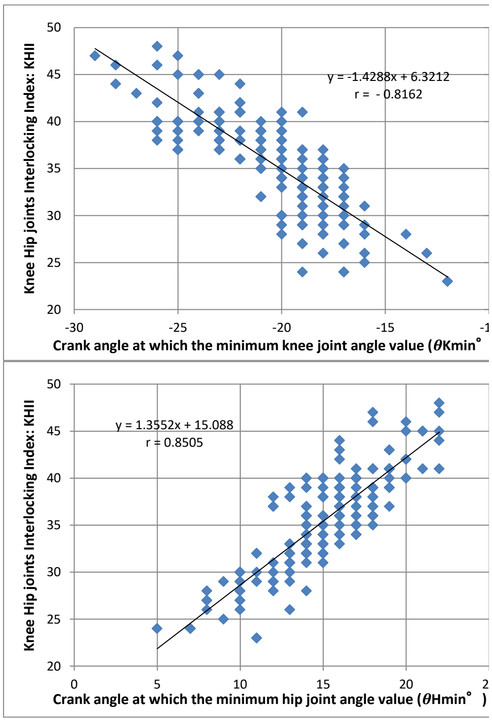

Figure 1. Relationship between the crank angle at which the minimum joint angle value is obtained and hip and knee joint interlocking index (KHII).

Thus, we focused on the movement of the ankle joint. When the crank moves from approximately 45° to 180°, the ankle is gradually plantar flexed. Conversely, when the crank rotates from 180° to 45°, the ankle is dorsiflexed. Close observation from the bottom dead center (BDC) to the TDC shows that the ankle bends, but before reaching the TDC, there may be movements from 270° to 360° where the degree of dorsiflexion decreases (to prevent the rider's heel from falling). To clarify this observation, when calculating the difference between the values of 270° and 330° of the ankle angle θA (330°) − θA (270°), a larger value corresponds with less heel-falling. This motion increases the pedal angle relative to the horizontal plane, resulting in a slower crank angle at which the pedal angle reaches its maximum. Therefore, Fig. 2 shows the relationship between the crank angle θPmax, where the pedal angle relative to the horizontal is the maximum value, and θA (330°) − θA (270°) or KHII. There is a good correlation between these values.

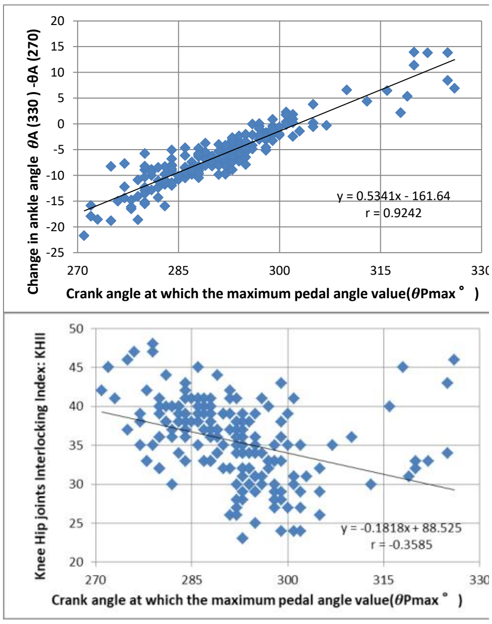

Figure 2. Relationship between ankle joint movement and hip/knee joint interaction from the crank angle corresponding with maximum pedal angle.

In order to prevent the heel from falling, the ankle joint begins to step in as a preliminary movement before reaching the TDC, maintaining a good relationship between the three joint angles. As a result, the knee and hip joints appear to step in conjunction with each other as the time comes closer to the start of the extension movement. It is easy to overlook this kind of movement when observing only the angle change of the ankle joint, and it seems to be the movement that becomes clear by observing the change of the pedal angle.

4. Conclusions

In this study, changes in the pedal angle and joint angle at each crank rotation angle were analyzed, and it was found that active plantar flexion of the ankle joint before passing the TDC enhances the cooperation to the joint angle changes of the hip joint and knee joint. In the future, it is planned to examine how the load and the cadence affect the pedaling operation.

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Conflicts of Interest: The authors declare no conflicts of interest.

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