BRAKING FORCES DURING BICYCLE PEDALING: AN EXAMINATION OF THE FULL CRANK ROTATION

Yuta Yamaguchi[1], Kohei Watanabe[2], Kenji Oishi[1], Wataru Fukuda[3], Tetsunari Nishiyama[1]

Nippon Sports Science University, Tokyo, Japan[1]
Chukyo University, Aichi, Japan[2]
Yokohama sports medical center, Yokohama, Japan[3]

Pedalling skills are evaluated using angular impluse of negative crank torque (I_{NCT}) that occurs in pulling phase (180-360° of crank rotation that 0° is top dead center. I_{NCT} has the effect of inhibit crank rotation ("braking force"). The aim of study was to obtain findings to reduce I_{NCT} for improving cyclists' pedalling skills. We examined the relationship between I_{NCT} and kinetic pedalling data through the full crank rotation. Fifteen male cyclists performed constant pedalling at 80%Vo_2max and 90rpm. Kinetic and kinematic pedalling data were measured by the pedal-shaped force platform (KISTLER) and by a 3D motion capture system (VICON). A negative correlation was indicated 80-250° of crank rotation between horizontal pedal force (Fh) and I_{NCT} ($p<0.05$). I_{NCT} occurring in pulling phase was affected by amount of Fh in pushing phase.

KEYWORDS: cyclist, pedalling skill, pedal force, joint moments, cranking phase.

INTRODUCTION: Bicycle pedalling consists of a pushing phase (0-180° of crank rotation that 0° is top dead center) and pulling phase (180-360°of crank rotation). Gregor et al (1985) suggested that the bulk of the force required to rotate the crank was generated in pushing phase. However, it is also evident that a negative crank torque is generated during the pulling phase (Kroff et al, 2007). Angular impulse of negative crank torque (I_{NCT}) that product of negative crank torque and time is related with pedalling skill. I_{NCT} has the effect of inhibit crank rotation (we call "braking force"), therefore it may be considered an indicator of efficient pedalling (Sanderson and Black, 2003). A number of studies have investigated improving cycling effectiveness by focussing on pulling phase lower limb movement and the affected of reducing the I_{NCT}. However, bicycle pedalling occurs at significant rotation speeds (in case of 90rpm, 540deg/s), therefore it considered to be difficult that to instantly switch downward

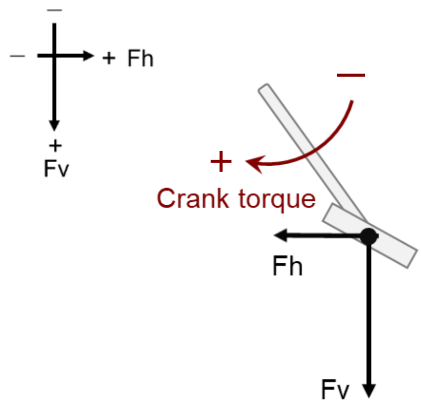

Figure 1: Illustration of vertical component pedal force (Fv), horizontal component pedal force (Fh) and crank torque.

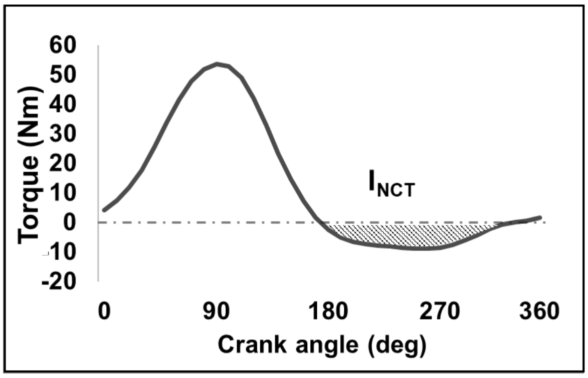

Figure 2: Mean data and standard error curve for crank torque (Nm). Defined I_{NCT} ("braking force") as area of negative value.

pedalling force to upward at near bottom dead center. We hypothesized that the I_{NCT} in the pulling phase would be affected by pedalling force during the pushing phase. The aim of study was to obtain findings to reduce I_{NCT} for improving cyclists' pedalling skills. We investigated the pedalling force, the kinetic data of the leg, and the relationship between them through the full crank rotation.

METHODS: Fifteen male cyclists (height: 170.8±4.5cm, weight: 67.4±8.3kg, mean ± SD) performed constant pedalling at 80%Vo_2max and a cadence of 90rpm in competitive cycling position. Pedalling force data were recorded at a rate of 1000 Hz by the pedal-shaped force platform (KISTLER). 3D coordinate of limb and crank were recorded at 200 Hz using a 3D motion capture system (VICON), were low pass filtered (8 Hz, zero lag Butterworth). The following pedalling force parameters were determined by means of previous study (Sanderson and Black, 2003); vertical component of pedal force (Fv), horizontal component of pedal force (Fh), crank torque (Figure 1) and I_{NCT} (Figure 2). Internal joint moments were calculated using previous study (Hull and Jorge, 1985). Ten consecutive revolutions were recorded from each participant, Mean and standard error in the variables were calculated every 10° of crank rotation. Pearson's correlations test was used to investigate the relationship between variables. The significance level was set at α = 0.05.

RESULTS: Figure 3 showed Fv and Fh data through a crank rotation in fifteen cyclists. A significantly correlation was indicated 130-310° of crank rotation between Fv and I_{NCT} ($p<0.05$). Similarly, a significantly correlation was indicated 80-250° of crank rotation between Fh and I_{NCT} ($p<0.05$). Fh indicated a significant correlation at an earlier crank angle (80° of crank rotation) than Fv it was. Figure 4 showed that typical example of significantly correlation between Fh and I_{NCT} in 120° of crank rotation. Furthermore, the Fh were significantly correlated with knee moments over a wide angular range in a crank rotation (0-300 and 340-360° of crank rotation, $p<0.05$). Figure 5 showed that typical example of significantly correlation between Fh and I_{NCT} in 120° of crank rotation.

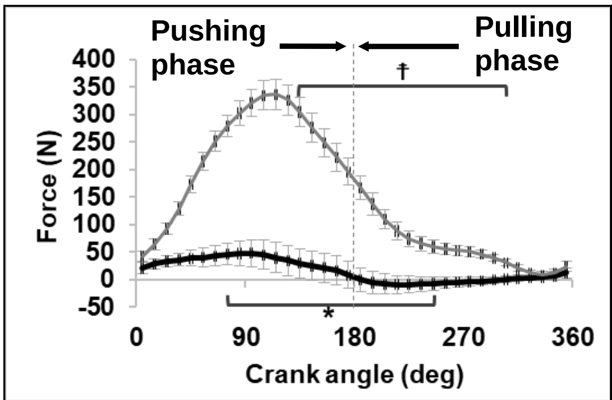

Figure 3: Mean curves for Fv (vertical pedal force, gray line) and Fh (horizontal pedal force, black line). †Significantly correlation between Fv and I_{NCT} ($p < 0.05$), *significantly correlation between Fh and I_{NCT} ($p < 0.05$).

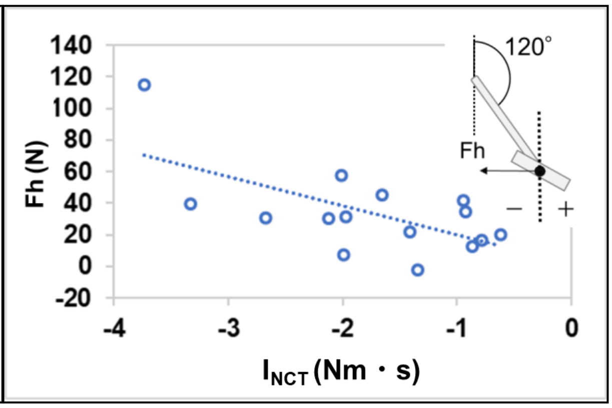

Figure 4: Relationship between I_{NCT} (angular impulse of negative crank torque) and Fh (horizontal pedal force) at 120° of crank rotation ($r = -0.707$, $p = 0.004$). The result suggested correlation between decrease Fh and decrease I_{NCT}.

DISCUSSION: As the aim of study was to obtain findings to reduce I_{NCT} for improving cyclists' pedalling skills. We investigated the relationship between I_{NCT} and kinetic pedalling data throughout the full crank rotation. An interesting result in the present study was correlation observed prior to the pulling phase. Previous studies of pedalling skill had focussed on the pulling phase and discussed the coordination pattern of lower limb movement with the force application profile on the pedal (Korff et al, 2007., Zameziati et al, 2006). The present study showed that Fv and Fh were significantly correlated with I_{NCT} at prior to the pulling phase. Korff et al (2007) suggested that I_{NCT} significantly decreased by pull up on the pedal, these results are similar to our results Fv correlated with I_{NCT} (130°- of crank rotation). On the other hand, Fh showed a significant correlation since middle of pushing phase (80°- of crank rotation). The pedaling consists of pushing and pulling phases, and in other words, it can be divided into a force exerting phases in forward (fourth to first quadrant) and backward direction (second to third quadrant). Therefore, it was important to manage the direction and magnitude of the force applied to the pedals in the second and third quadrants to reduce I_{NCT}. Further, Fh and knee moments were

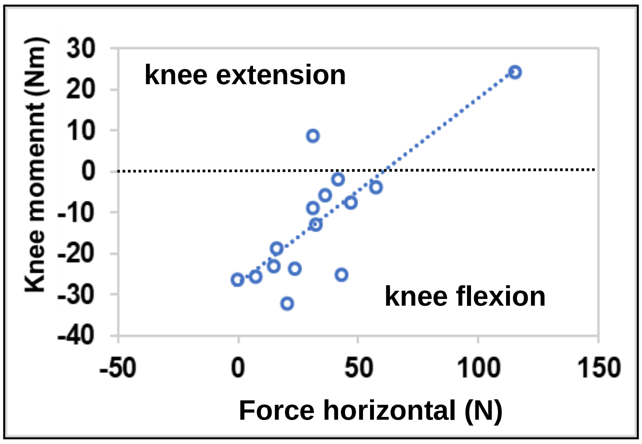

Figure 5: Relationship between Fh and knee moments at 120° of crank rotation (r = 0.809, p = 0.001). This relationship was observed in 0-300 and 340-360° of crank rotation (not shown in this Figure).

significantly correlated over a wide angular range in a crank rotation. These results suggested that Fh is closely related knee moments. Gregor et al (1985) suggested knee flexion moments occur in pushing phase, and Candotti et al (2009) suggested cyclists exert less in knee extensor muscle activity at pushing phase than triathletes. The previous findings support our results that a significant correlation between Fh and knee joint moment was observed over a wide angular range in a crank rotation. From their findings, it was inferred that the knee joint kinetic plays an important role in reducing I_{NCT}.

CONCLUSION: I_{NCT} meaning "braking force" is affected by knee moments activation pattern during the pushing phase. New findings of pedalling skill were indicated in this study, which was useful findings for cyclists or coaches improving them.

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