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

Yuta Yamaguchi¹, Kohei Watanabe², Kenji Oishi¹, Wataru Fukuda³, Tetsunari Nishiyama¹

Nippon Sports Science University, Tokyo, Japan¹
Chukyo University, Aichi, Japan²
Yokohama sports medical center, Yokohama, Japan³

Pedalling skills are evaluated using angular impulse of negative crank torque (INCT) that occurs in pulling phase (180-360° of crank rotation that 0° is top dead center. INCT has the effect of inhibit crank rotation ("braking force"). The aim of study was to obtain findings to reduce INCT for improving cyclists' pedalling skills. We examined the relationship between INCT and kinetic pedalling data through the full crank rotation. Fifteen male cyclists performed constant pedalling at 80%Vo₂max 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 INCT (p<0.05). INCT 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 (INCT) that product of negative crank torque and time is related with pedalling skill. INCT 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 INCT. 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.](image)

![Figure 2: Mean data and standard error curve for crank torque (Nm). Defined INCT ("braking force") as area of negative value.](image)
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%V_{O2max} 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 $\alpha = 0.05$.

**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](image1.png)  
**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](image2.png)  
**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 INCT at prior to the pulling phase. Korff et al (2007) suggested that INCT significantly decreased by pull up on the pedal, these results are similar to our results Fv correlated with INCT (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 INCT. Further, Fh and knee moments were 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 INCT.

**CONCLUSION:** INCT 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.

**REFERENCES**


**ACKNOWLEDGEMENTS:** This research is cooperated with students of Nippon Sports Science University. We thank all subjects for their participant in this study. We would also like to thank Prof. Michiyoshi Ae for his advice with data analysis.