

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

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Pedalling skills are evaluated using angular impulse 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% $V_{O_2max}$  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 ( $F_h$ ) and  $I_{NCT}$  ( $p < 0.05$ ).  $I_{NCT}$  occurring in pulling phase was affected by amount of  $F_h$  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

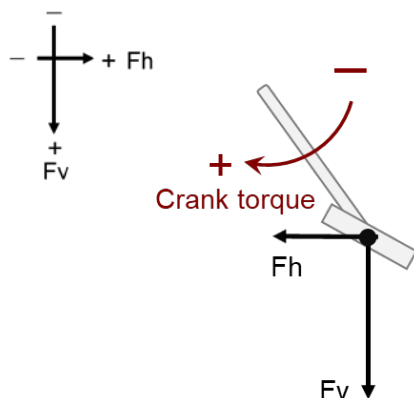


Figure 1: Illustration of vertical component pedal force ( $F_v$ ), horizontal component pedal force ( $F_h$ ) and crank torque.

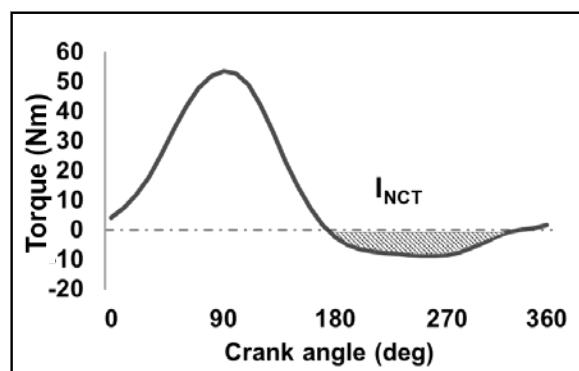
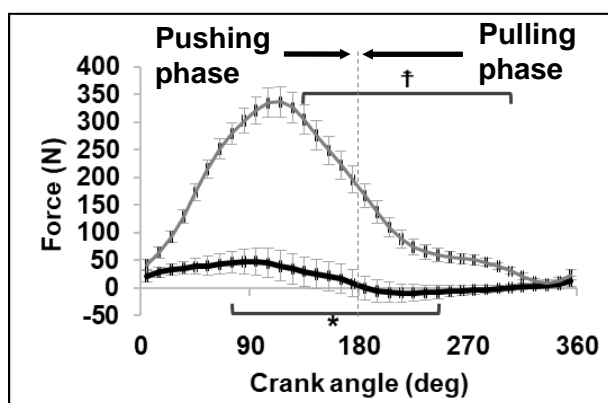


Figure 2: Mean data and standard error curve for crank torque (Nm). Defined  $I_{NCT}$  (“braking force”) as area of negative value.

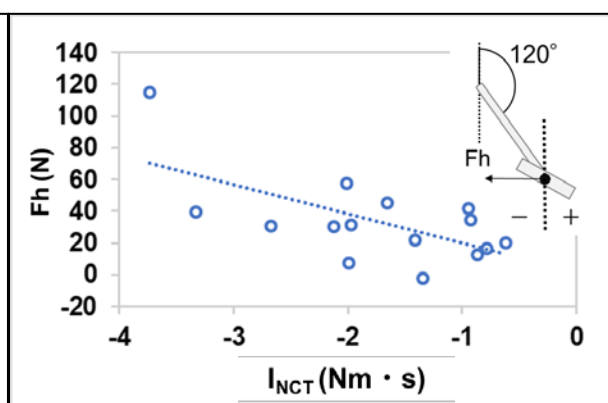
downward pedalling force to upward at near bottom dead center. We hypothesized that the  $I_{NCT}$  in the pulling phase would be affected by pedalling force during the pushing phase. The aim of study was to obtain findings to reduce  $I_{NCT}$  for improving cyclists' pedalling skills. We investigated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

**METHODS:** Fifteen male cyclists (height:  $170.8 \pm 4.5$ cm, weight:  $67.4 \pm 8.3$ kg, mean  $\pm$  SD) performed constant pedalling at  $80\%V_{O_2max}$  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 ( $F_v$ ), horizontal component of pedal force ( $F_h$ ), 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  $10^\circ$  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  $F_v$  and  $F_h$  data through a crank rotation in fifteen cyclists. A significantly correlation was indicated  $130-310^\circ$  of crank rotation between  $F_v$  and  $I_{NCT}$  ( $p < 0.05$ ). Similarly, a significantly correlation was indicated  $80-250^\circ$  of crank rotation between  $F_h$  and  $I_{NCT}$  ( $p < 0.05$ ).  $F_h$  indicated a significant correlation at an earlier crank angle ( $80^\circ$  of crank rotation) than  $F_v$  it was. Figure 4 showed that typical example of significantly correlation between  $F_h$  and  $I_{NCT}$  in  $120^\circ$  of crank rotation. Furthermore, the  $F_h$  were significantly correlated with knee moments over a wide angular range in a crank rotation ( $0-300$  and  $340-360^\circ$  of crank rotation,  $p < 0.05$ ). Figure 5 showed that typical example of significantly correlation between  $F_h$  and  $I_{NCT}$  in  $120^\circ$  of crank rotation.



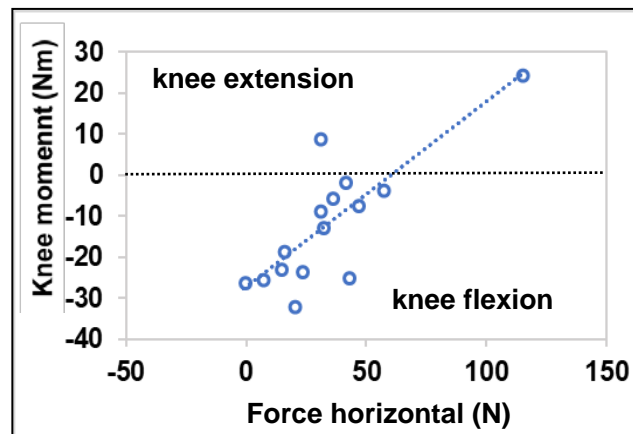
**Figure 3: Mean curves for  $F_v$  (vertical pedal force, gray line) and  $F_h$  (horizontal pedal force, black line). †Significantly correlation between  $F_v$  and  $I_{NCT}$  ( $p < 0.05$ ), \*significantly correlation between  $F_h$  and  $I_{NCT}$  ( $p < 0.05$ ).**



**Figure 4: Relationship between  $I_{NCT}$  (angular impulse of negative crank torque) and  $F_h$  (horizontal pedal force) at  $120^\circ$  of crank rotation ( $r = -0.707$ ,  $p = 0.004$ ). The result suggested correlation between decrease  $F_h$  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  $I_{NCT}$  ( $130^\circ$ - of crank rotation). On the other hand, Fh showed a significant correlation since middle of pushing phase ( $80^\circ$ - 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  $120^\circ$  of crank rotation ( $r = 0.809$ ,  $p = 0.001$ ). This relationship was observed in  $0-300$  and  $340-360^\circ$  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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