INCREASING POWER OUTPUT AND MOVEMENT OPTIMIZATION IN CYCLING: INSIGHTS FROM A FULLY INSTRUMENTED ERGOMETER

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We hypothesized that the saddle vertical force would be a critical parameter to explain the sit-to-stand transition during cycling. Twenty-five participants were required to pedal at six different powers ranging from 20 (1.6 ± 0.3 $W.kg^{-1}$) to 120% (9.6 ± 1.6 $W.kg^{-1}$) of their Sit-to-Stand Transition Power (SSTP) at 90 RPM. Five 6-component sensors recorded the loads applied on the saddle, pedals and handlebars. The results showed that the saddle vertical force decreased with increasing cycling power, from a static position on the bicycle (5.30 ± 0.50 $N.kg^{-1}$) to 120% of SSTP (0.68 ± 0.49 $N.kg^{-1}$). Pedal and handlebar force directions were reversed around SSTP, suggesting that the seated position may become constraining in these pedalling conditions. These results suggest that the saddle vertical reaction force may be predictive of the sit-to-stand transition in cycling, and that pedalling in the seated position at high crank forces add constraints on the cyclist, explaining the spontaneous change in coordination mode.

KEY WORDS: seated position, standing position, 6-component sensors.

INTRODUCTION: Most of the investigations in cycling biomechanics focused on the lower limb actions despite evidences that the whole body can be involved, and only a few studies reported the forces applied on the handlebar and/or on the saddle (Bolourchi & Hull, 1985; Wilson & Bush, 2007). However, the spontaneous full-body organisation in response to increasing pedalling power still needs to be described. The purpose of this study was to measure the force patterns applied by the cyclist on all his supports in order to explain why a spontaneous transition from the seated to the standing position is observed for a given cycling power. By using the simplest definitions of the seated (a vertical force applied on the saddle), and standing positions (lack of vertical force applied on the saddle), we hypothesized that the saddle vertical reaction force would be the critical parameter to explain this transition. Indeed, given the constraint of increasing pedal forces, the body weight may no longer be supported by the saddle, which may lead the cyclist to create additional forces on his supports in order to keep pedalling seated at a given level of efficient pedal forces (i.e. crank power for a given pedalling cadence).

METHODS: After a standardized bike positioning, 25 non-elite cyclists (23.2 ± 3.6 y, 1.77 ± 0.06 m, 71.5 ± 9.1 kg) were weighted on the ergocycle (LODE, Groningen, Netherlands) in order to measure a static level of saddle vertical force. This weight was determined with a horizontal crank position, and with 0.5 m between the two hands in prone position on the flat handlebar. Then, they performed an incremental test to determine their spontaneous Sit-to-Stand Transition Power (SSTP). In this protocol, active bouts of effort (20 s at 200 W + 25 W by increment) were alternated with recovery periods (40 s at 50 W), with a 90 RPM pedalling cadence. The power corresponding to SSTP was defined as the power at which the participant rose spontaneously from the saddle during 10 s. After five minutes of rest, 6 randomized trials of 10 s were performed in the seated position, with cycling powers ranging from 20 to 120% of SSTP, with 3 minutes of passive rest between each.
During these trials, the reaction forces applied on the handlebars, the saddle tube, and the pedals were recorded from three tubular sensors (SENSIX, Poitiers, France), and by two instrumented

pedals (I-Crankset-1, SENSIX, Poitiers, France) at a sampling frequency of 1 kHz. Three passive markers were positioned on each sensor, and their position recorded with twelve infrared cameras (VICON, Oxford, United-Kingdom) at 200 Hz. Kinetic and kinematic data were synchronized using Nexus 1.7.1 system (VICON, Oxford, United-Kingdom) and filtered using a 4th order, zero phase-shift, low-pass Butterworth with a 8 Hz cutoff frequency (McDaniel, Behjani, Elmer, Brown, & Martin 2014). Data analyses were performed using Scilab 5.4.0 (SCILAB, Scilab Enterprises). In the present study, only the vertical component of the 3D reaction forces expressed in the laboratory reference frame were considered. All statistical analyses were performed using the STATISTICA software (STATSOFT, Maisons-Alfort, France). A p-value of 0.05 was defined as the level of statistical significance.

RESULTS: The cycling power corresponding to the sit-to-stand transition was 568 ± 93 W (8.0 ± 1.4 W.kg^{-1}). Thus, cycling powers corresponding from 20 to 120% ranged from 114 ± 19 W (1.6 ± 0.3 W.kg^{-1}) to 682 ± 111W (9.6 ± 1.6 W.kg^{-1}). Because of the constant pedaling cadence imposed, increases in power output lead to equivalent increases in effective force production on the pedals.
The static vertical reaction force on the saddle was 5.30 ± 0.50 N.kg^{-1}.
The minimum and maximum saddle vertical reaction forces observed during one pedal revolution for each cycling power are presented in Figure 1A. The minimum reaction force decreased with increasing cycling power by 87% from a static position on the bicycle (5.30 ± 0.50 N.kg^{-1}) to 120% of SSTP (0.68 ± 0.49 N.kg^{-1}). SSTP corresponded to a minimum value of saddle vertical force of 0.99 ± 0.50 N.kg^{-1}. Saddle vertical reaction force patterns are represented in a descriptive purpose in Figure 1B.

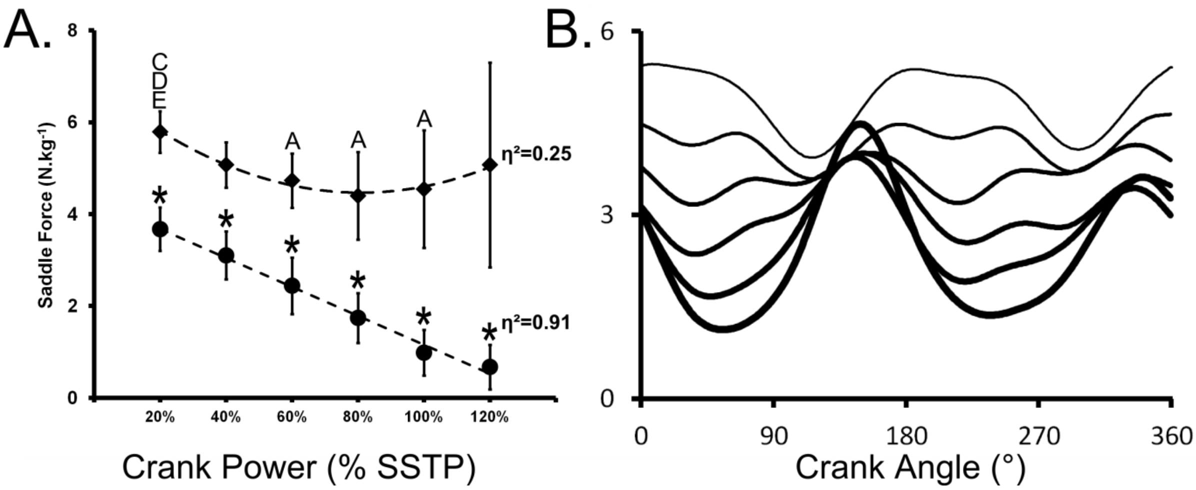

Figure 1: A. Maximum and minimum saddle vertical reaction force. *: difference with all other crank powers. A, B, C, D, E, and F: difference in comparison to 20, 40, 60, 80, 100, and 120% of SSTP, respectively. η²: partial eta-squared. B. Saddle vertical reaction force patterns along one right crank pedal cycle averaged for the participants. The wider line corresponds to the higher crank power.

The minimum and maximum pedal and handlebar vertical reaction forces during one pedal revolution are presented in Figure 2. Maximum pedal vertical reaction forces increased with cycling power (R^2 = 0.998 and 0.999 for the left, and right pedal, respectively), while minimum pedal vertical reaction forces decreased with cycling power and became negative above 80% of SSTP.
Minimum handlebar vertical reaction forces decreased with cycling power and became negative from SSTP.

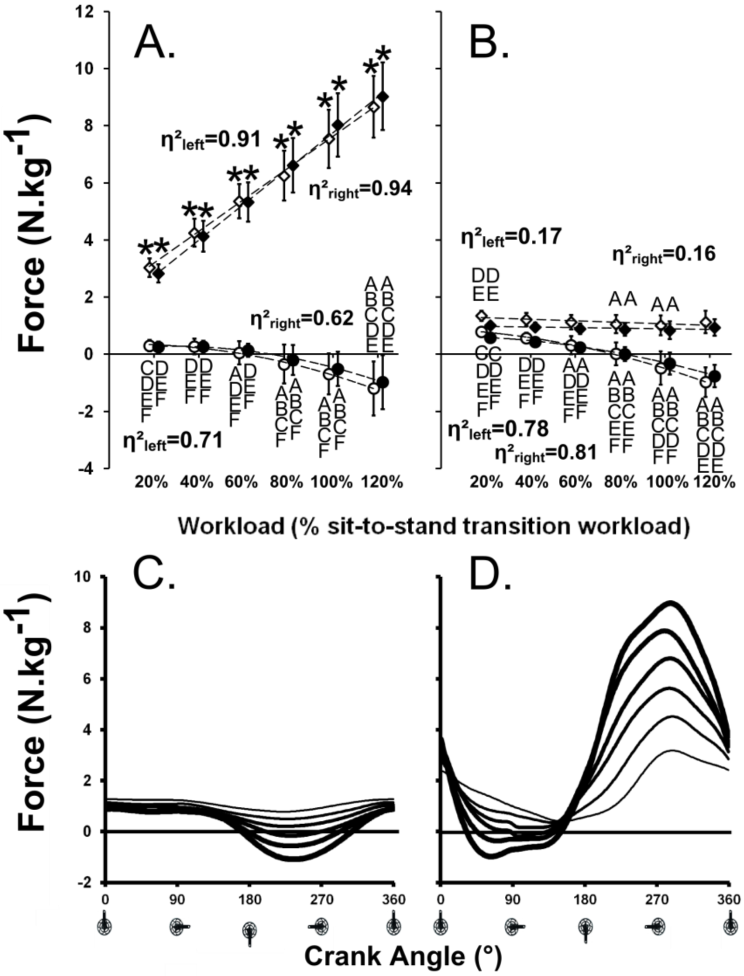

Figure 2: Minimum (dots) and maximum (diamonds) left (white), and right (black) vertical reaction forces. A. Pedals. B. Handlebars. *: difference with all other crank powers. A, B, C, D, E, and F: difference in comparison to 20, 40, 60, 80, 100, and 120% of SSTP, respectively. η²: partial eta-squared. C. and D. Left handlebar and left pedal vertical reaction force patterns along one right crank pedal cycle averaged for the participants, respectively. The wider line corresponds to the higher crank power.

DISCUSSION: In the present investigation, we hypothesized that the saddle vertical force would decrease with increasing pedal forces and would predict the sit-to-stand transition in cycling. Our results support our hypothesis as a strongly linear relationship was observed between the saddle vertical reaction force and cycling power (Figure 1). The sit-to-stand transition occurred at minimum saddle vertical force of about 1 $N.kg^{-1}$. Handlebar and pedal reaction forces also showed interesting evolutions, with their minima tending to be negative around SSTP (Figure 2). A plausible explanation may be that the inversion in the direction of these forces corresponds to a trend to counteract the upward acceleration linked to upward pedal reaction forces (i.e. pulling on the pedal and on the handlebar to remain seated). Previous studies have shown that pulling on the pedals, although increasing the mechanical effectiveness of pedaling, was detrimental to the metabolic efficiency (Edwards, Jobson, George, Day, & Nevill, 2009; Korff, Romer, Mayhew, & Martin, 2007), and was a strategy opposite to the one employed by elite cyclists (Coyle et al., 1991).
Similarly to pedal traction, pulling on the handlebar is associated with an important metabolic cost, increasing with the pedal force (McDaniel, Subudhi, & Martin, 2005).
However, at the power output at which the part of the body weight supported by the saddle was compensated by the upward pedal reaction forces, both pedal and handlebar pulling forces shared a common interest in counterbalancing these pedal forces, and allowing to stay seated by adding

vertical force on the saddle. Given the length of the measurements in this study, the downward forces created on the pedals and handlebars allowed to temporarily keep pedaling in the seated position despite their metabolic cost, a strategy presumably impossible to hold for longer durations. These results suggest that the standing position may be preferred at a given level of pedal force due to an increase in the necessity to create these downward reaction forces and/or because of the fact that the saddle becomes useless to carry the body weight.

CONCLUSION: Because of the high vertical reaction forces applied by the pedals at high crank power, the saddle vertical force dramatically decreased, which may have triggered the sit-to-stand transition. This spontaneous transition occurred at minimum saddle vertical force of about 1 $N.kg^{-1}$. The strong relationship between saddle vertical force and cycling power for a given pedaling cadence suggests that SSTP can be predicted with this value of saddle vertical force. Behaviors counteracting the upward vertical pedal forces were observed around the power corresponding to SSTP by studying handlebar and pedal forces, suggesting that the spontaneous choice to rise in the standing position may be a solution to reduce these constraints. In addition, this study suggests that improving bike settings and considering the specificities imposed by high force pedaling on the whole body during training may improve cycling performance. Clinicians, researchers, and manufacturers trying to understand the etiology of groin injuries and erectile dysfunction associated with cycling (Lowe, Schrader, & Breitenstein, 2004; Carpes, Dagnese, Kleinpaul, Martins, & Mota, 2009) should also consider which factors can influence saddle forces.

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