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A reduction of the saddle vertical force triggers the sit–stand transition in cycling

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ABSTRACT

The purpose of the study was to establish the link between the saddle vertical force and its determinants in order to establish the strategies that could trigger the sit–stand transition. We hypothesized that the minimum saddle vertical force would be a critical parameter influencing the sit–stand transition during cycling. Twenty-five non-cyclists were asked to pedal at six different power outputs from 20% (1.6 ± 0.3 W kg^{-1}) to 120% (9.6 ± 1.6 W kg^{-1}) of their spontaneous sit–stand transition power obtained at 90 rpm. Five 6-component sensors (saddle tube, pedals and handlebars) and a full-body kinematic reconstruction were used to provide the saddle vertical force and other force components (trunk inertial force, hips and shoulders reaction forces, and trunk weight) linked to the saddle vertical force. Minimum saddle vertical force linearly decreased with power output by 87% from a static position on the bicycle (5.30 ± 0.50 N kg^{-1}) to power output = 120% of the sit–stand transition power (0.68 ± 0.49 N kg^{-1}). This decrease was mainly explained by the increase in instantaneous pedal forces from 2.84 ± 0.58 N kg^{-1} to 6.57 ± 1.02 N kg^{-1} from 20% to 120% of the power output corresponding to the sit–stand transition, causing an increase in hip vertical forces from -0.17 N kg^{-1} to 3.29 N kg^{-1}. The emergence of strategies aiming at counteracting the elevation of the trunk (handlebars and pedals pulling) coincided with the spontaneous sit–stand transition power. The present data suggest that the large decrease in minimum saddle vertical force observed at high pedal reaction forces might trigger the sit–stand transition in cycling.

1. Introduction

Seated (SEAT) and Standing (STAND) are the two common positions chosen during bicycle locomotion. Several studies comparing the two positions have shown that spontaneous pedaling cadences are slower in STAND than in SEAT position (Harnish et al., 2007; Lucía et al., 2001), and that the STAND position is associated with the highest power outputs (McLester et al., 2004; Millet et al., 2002; Reiser et al., 2002). Furthermore, the fact that cyclists tend to spontaneously switch from SEAT to STAND when high force applied to the pedals are needed (i.e. during fast accelerations or steep climb ascensions) suggests that the change in position favors a maximization of the pedal reaction forces (Hansen and Waldeland, 2008). However, the parameters leading to select one position over the other one in order to produce a given combination of pedal reaction force and power output need to be clarified.

Many attempts have been made to understand the mechanisms underlying these positions, particularly to determine the superiority of the STAND position to produce higher power outputs and pedal reaction forces. From a joint torque perspective, a study using the moment cost function defined by Gonzalez and Hull (1989) presented a slight reduction of this cost function above the sit–stand transition power (Poirier et al., 2007), whereas lower limbs net joint torques have been described by others as increasing in STAND position for both the ankle plantarflexion and the knee extension (Caldwell et al., 1999; Li and Caldwell, 1998). From a metabolic energy consumption perspective, the SEAT position has been shown to be more efficient to produce lower power outputs (Ryschon and Stray-Gundersen, 1991; Tanaka et al., 1996), and equally efficient as the STAND one to produce high power

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outputs (Harnish et al., 2007; Millet et al., 2002; Tanaka et al., 1996). Regarding studies using electromyography, the literature suggests that differences in the temporal profiles and in the level of activation of the muscles could be expected between SEAT and STAND (Li and Caldwell, 1998; Hug et al., 2011). For example, Duc et al. (2008) reported a slight decrease for the *semimembranosus* activation from SEAT to STAND, whereas Li and Caldwell (1998) reported increased activations of the *gluteus maximus, tibialis anterior* and *rectus femoris* muscles in STAND position. These differences may influence the coordination patterns in both positions (De Marchis et al., 2013). Nonetheless, the muscle synergies activated in the two positions may remain similar (Hug et al., 2011) and the literature does not provide evidences of an advantage of one position against the other at this level.

Since there is no obvious reason to prefer the STAND rather than the SEAT position to produce one given power output, we propose in this study to reverse the questioning and to wonder why the SEAT position is no longer chosen, instead of why the STAND position may become optimal beyond a given level of crank power. To test our hypotheses, we first propose a criterion that could clearly distinguish the two positions: the SEAT position is characterized by a contact between the cyclist and the saddle (i.e. a vertical force is applied by the cyclist on the saddle) whereas the STAND position is characterized by the absence of this vertical force. In this definition, the force applied by the cyclist on the saddle (and reciprocally) is of central interest, and the sit–stand transition is defined by the disappearance of this force.

To the best of our knowledge, only three studies measured saddle forces in cycling. The first one presented saddle force at three pedaling cadences and described a double period pattern with maximum magnitudes decreasing as cadence decreases (Bolourchi and Hull, 1985). However, the second study did not found this double period pattern (Stone and Hull, 1995) while the third one observed both of these patterns (Wilson and Bush, 2007). To better understand this phenomenon, we propose to investigate the saddle force patterns. According to Newton's second law, this force is the result of a simple mechanical interaction between the cyclist's body weight and the other forces applied on his bicycle. Consequently, a downward vertical force applied on the pedal would result by reaction in an upward force on the hip, accelerating the trunk in an upward direction, and decreasing the force applied on the saddle by the cyclist. Therefore, we propose to measure vertical forces applied on the saddle, in complement with the other forces acting on the trunk of the cyclist (i.e. hips and shoulders reaction forces, trunk weight, and acceleration of the trunk's center-of-mass) at different pedal reaction forces. The aims of this study are to validate a full-body inverse dynamics model of cycling and to test the hypothesis that saddle vertical force would decrease and reach values close to zero with increasing pedal forces, making the SEAT position irrelevant given its definition and leading the cyclist to spontaneously adopt the STAND position.

2. Methods

2.1. Participants

Twenty five male sport science students (23.2 ± 3.6 y, height 1.77 ± 0.06 m, body mass 71.5 ± 9.1 kg) volunteered for this investigation. The participants were non-cyclists and belonged to category 4–5 according to Ansley and Cangley (2009) classification. Each participant was informed of the experimental procedure and signed an informed consent form prior to the study. The study was conducted in accordance with the declaration of Helsinki and was approved by the University of Toulouse ethical committee. Participants were asked to avoid high-intensity or exhaustive exercise at least 72 h before the laboratory trials.

2.2. Experimental protocol

The cycling tests were performed using an electromagnetically braked cycle ergometer Excalibur (LODE, Groningen, Netherlands). To limit bike positioning effects, standardized settings were adopted. Briefly, pedal cleats were positioned under the first metatarsal bone (Viker and Richardson, 2013), the saddle height was set at a 150° knee angle during maximum leg extension, the seat tube angle was set to 73°, the crank length was 0.17 m in length and the handlebar was flat. The latter was positioned to standardize drop (the vertical distance between the top of the saddle and the handlebar mediolateral axis) and reach (the horizontal distance between the back of the saddle and the handlebar mediolateral axis) lengths according to torso and arm lengths (De Vey Mestdagh, 1998). The mediolateral positioning of the two hands on the handlebar was left up to the participant (handlebar width: 0.7 m).

After bike positioning, participants were first weighed on the cycle ergometer in order to measure a static level of saddle vertical force (representing 0% of the sit–stand transition power). This weighing was made with the shoes fixed on the pedals, the hands on the handlebars, and the cranks in horizontal position. Then, after a five-minute warm-up at 100 W, they performed a cycling test to determine their spontaneous sit–stand transition power (Fig. 1). In this test, phases of 20 s with a starting power output of 200 W incremented by 25 W at each step rest were alternated with rest phases of 40 s at a power output of 50 W. The sit–stand transition power was considered as the power output at which participants rose from the saddle during at least 10 s. A visual feedback of the pedaling cadence was provided to the participants who were instructed to maintain it at 90 ± 5 rpm.

Then, after a five-minute rest period, participants performed six randomized trials at power output corresponding to 20%, 40%, 60%, 80%, 100% or 120% of their sit–stand transition power and were asked to remain seated throughout these sequences. Each pedaling trial began with a minimum stabilization time of 10 s at the target power output at 90 rpm, followed by 10 s of data recording. Three minutes of passive rest were given between each of these six trials.

2.3. Data acquisition

The 3D force and moment components applied to the handlebar, saddle tube and pedals were recorded from three tubular sensors (SENSIX, Poitiers, France), and by two instrumented pedals (I-Crankset-1, SENSIX, Poitiers, France) at 1 kHz (Fig. 2). According to the manufacturer, these dynamometers had a maximum 1% error on each direction (combining linearity and hysteresis errors), and a maximum 1.5% error on the 6 components combination.

Kinematics data were collected from 56 passive markers recorded by twelve infrared cameras (VICON, Oxford, United-Kingdom) at 200 Hz. The kinetics sensors' reference points were defined as shown in Fig. 2. The ankle (because of the impossibility to stick one kinematic marker on the *medial malleolus* in reason of the crank proximity), shoulder and hip joint centers were located using the SCoRE method (Ehrig et al., 2006). For this method, a preliminary recording asking the participants to repeat flexion–extension, abduction–adduction and circumduction of the tested joint allowed the localization of their centers-of-rotation (Begon et al., 2007). Body segments masses, center-of-mass positions, and radii of gyration were defined in accordance with De Leva's (1996) anthropometric charts. All kinetics and kinematics data were recorded in three-dimensions.

2.4. Data reduction and analysis

Kinetics and kinematics 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 et al., 2014). In order to determine the factors affecting the saddle vertical force, the trunk was represented (comprising the head and the pelvis) as being submitted to external forces applied on the shoulders, hips, and saddle contact. The following equality has been computed by isolating the head and trunk solid according to Newton's second law:

$$F_s = m_t a_t - \left(W_t + F_h + F_{sh}\right) \tag{1}$$

where m_t is the mass of the head and trunk solid according to De Leva's anthropometric chart, a_t is the linear acceleration of the head and trunk center-of-mass, W_t is the sum of the head and trunk weights, F_s is the saddle reaction force obtained from the saddle tube sensor, F_{sh} is the shoulder reaction force calculated by a inverse dynamics method from the handlebar sensors, and F_h the hip reaction force calculated by the inverse dynamics method from the pedal sensors. To compute F_h and F_{sh}, a classic inverse dynamic process was used (Winter, 1990). In this method, body-segments from upper and lower limbs were considered rigid and interconnected by frictionless joints and their inertial parameters were derived from the scaling equations (De Leva, 1996). Given the aims of the study, only the vertical components in Eq. (1) were considered. This model is illustrated in Fig. 3. Pedal forces were converted from the local to the global coordinate system by using a rotation matrix based on three kinematic markers placed on a strip embedded externally to the pedals. The entire data processing was performed using custom-made codes written in Scilab 5.4.0 (SCILAB, Scilab Enterprises). All the data were normalized to the subject's body mass. During the crank cycle corresponding to the minimum saddle vertical force observed

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