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Antony Costes, Nicolas A Turpin, David Villeger, Pierre Moretto, Bruno Watier. A reduction of the saddle vertical force triggers the sit–stand transition in cycling. Journal of Biomechanics, 2015, 48 (12), pp.2998-3003. 10.1016/j.jbiomech.2015.07.035. hal-01663013

# HAL Id: hal-01663013 https://laas.hal.science/hal-01663013

Submitted on 13 Dec 2017

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1	A REDUCTION OF THE SADDLE VERTICAL FORCE TRIGGERS THE SIT-STAND
2	TRANSITION IN CYCLING
3	
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21	Running Title: "Triggers of the Sit-Stand Transition in Cycling"

22 Word count: 3576 (abstract: 235).

25 The purpose of the study was to establish the link between the saddle vertical force and its 26 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 27 sit-stand transition during cycling. Twenty-five non-cyclists were asked to pedal at six different 28 power outputs from 20% (1.6±0.3W.kg<sup>-1</sup>) to 120% (9.6±1.6W.kg<sup>-1</sup>) of their spontaneous sit-stand 29 30 transition power obtained at 90RPM. Five 6-components sensors (saddle tube, pedals and 31 handlebars) and a full-body kinematic reconstruction were used to provide the saddle vertical force 32 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 33 power output by 87% from a static position on the bicycle  $(5.30\pm0.50$  N.kg<sup>-1</sup>) to power 34 35 output=120% of the sit-stand transition power  $(0.68\pm0.49N.kg^{-1})$ . This decrease was mainly explained by the increase in pedal forces from 2.84±0.58 N.kg<sup>-1</sup> to 6.57±1.02 N.kg<sup>-1</sup> from 20 to 36 120% of the power output corresponding to the sit-stand transition, causing an increase in hip 37 vertical forces from -0.17N.kg<sup>-1</sup> to 3.29N.kg<sup>-1</sup>. The emergence of strategies aiming at counteracting 38 39 the elevation of the trunk (handlebars and pedals pulling) coincided with the spontaneous sit-stand 40 transition power. The present data suggest that the large decrease in minimum saddle vertical force 41 observed at high pedal reaction forces might trigger the sit-stand transition in cycling.

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# Key Words: INVERSE DYNAMICS, PEDALING, SEAT, STAND

**1. Introduction** 

#### 45

46 Seated (SEAT) and Standing (STAND) are the two common positions chosen during bicycle 47 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 48 49 that the STAND position is associated with the highest power outputs (McLester et al., 2004; Millet 50 et al., 2002; Reiser et al., 2002). Furthermore, the fact that cyclists tend to spontaneously switch 51 from SEAT to STAND when high force applied to the pedals are needed (i.e. during fast 52 accelerations or steep climb ascensions) suggests that the change in position favors a maximization 53 of the pedal reaction forces (Hansen and Waldeland, 2008). However, the parameters leading to 54 select one position over the other one in order to produce a given combination of pedal reaction 55 force and power output need to be clarified.

56 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 57 58 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-59 stand transition power (Poirier et al., 2007), whereas lower limbs net joint torques have been 60 61 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 62 perspective, the SEAT position has been shown to be more efficient to produce lower power outputs 63 64 (Ryschon and Stray-Gundersen, 1991; Tanaka et al., 1996), and equally efficient as the STAND one to produce high power outputs (Harnish et al., 2007; Millet et al., 2002; Tanaka et al., 1996). 65 66 Regarding studies using electromyography, the literature suggests that differences in the temporal 67 profiles and in the level of activation of the muscles could be expected between SEAT and STAND 68 (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.

75 Since there is no obvious reason to prefer the STAND rather than the SEAT position to 76 produce one given power output, we propose in this study to reverse the questioning and to wonder 77 why the SEAT position is no longer optimal, instead of why the STAND position becomes optimal 78 beyond a given level of crank power. To test our hypotheses, we first propose a criterion that could 79 clearly distinguish the two positions: the SEAT position is characterized by a contact between the 80 cyclist and the saddle (i.e. a vertical force is applied by the cyclist on the saddle) whereas the 81 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 82 83 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 84 85 cadences and described a double period pattern with maximum magnitudes decreasing as cadence 86 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 87 Bush, 2007). To better understand this phenomenon, we propose to investigate the saddle force 88 89 patterns. According to Newton's second law, this force is the result of a simple mechanical 90 interaction between the cyclist's body weight and the other forces applied on his bicycle. 91 Consequently, a downward vertical force applied on the pedal would result by reaction in an upward 92 force on the hip, accelerating the trunk in an upward direction, and decreasing the force applied on 93 the saddle by the cyclist. Therefore, we propose to measure vertical forces applied on the saddle, in 94 complement with the other forces acting on the trunk of the cyclist (i.e. hips and shoulders reaction 95 forces, trunk weight, and acceleration of the trunk's center-of-mass) at different pedal reaction 96 forces. The aims of this study are to validate a full-body inverse dynamics model of cycling and to 97 test the hypothesis that saddle vertical force would decrease and reach values close to zero with 98 increasing pedal forces, making the SEAT position irrelevant given its definition and leading the 99 cyclist to spontaneously adopt the STAND position.

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- **2. Methods**
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- 103 2.1. Participants
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Twenty five male sport science students  $(23.2 \pm 3.6 \text{ y}, \text{ height } 1.77 \pm 0.06 \text{ m}, \text{ body mass}$ 106  $71.5 \pm 9.1 \text{ kg}$ ) volunteered for this investigation. The participants were non-cyclists and belonged to 107 category 4-5 according to Ansley and Cangley (2009) classification. Each participant was informed 108 of the experimental procedure and signed an informed consent form prior to the study. The study 109 was conducted in accordance with the declaration of Helsinki and was approved by the University 110 of Toulouse ethical committee. Participants were asked to avoid high-intensity or exhaustive 111 exercise at least 72 hours before the laboratory trials.

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# 113 2.2. Experimental Protocol

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115 The cycling tests were performed using an electromagnetically braked cycle ergometer 116 Excalibur (LODE, Groningen, Netherlands). To limit bike positioning effects, standardized settings 117 were adopted. Briefly, pedal cleats were positioned under the first metatarsal bone (Viker and 118 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).

125 After bike positioning, participants were first weighed on the cycle ergometer in order to 126 measure a static level of saddle vertical force (representing 0% of the sit-stand transition power). 127 This weighing was made with the shoes fixed on the pedals, the hands on the handlebars, and the 128 cranks in horizontal position. Then, after a five-minute warm-up at 100W, they performed a cycling 129 test to determine their spontaneous sit-stand transition power (Figure 1). In this test, phases of 20 s 130 with a starting power output of 200 W incremented by 25 W at each step rest were alternated with 131 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 132 133 the pedaling cadence was provided to the participants who were instructed to maintain it at 134  $90 \pm 5$  RPM.

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# PLEASE INSERT FIGURE 1

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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 90RPM, followed by 10s of data recording. Three minutes of passive rest were given between each of these six trials.

#### 2.3. Data acquisition

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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 (Figure 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.

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- 152

PLEASE INSERT FIGURE 2

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154 Kinematics data were collected from 56 passive markers recorded by twelve infrared 155 cameras (VICON, Oxford, United-Kingdom) at 200 Hz. The kinetics sensors' reference points were defined as shown in Figure 2. The ankle (because of the impossibility to stick one kinematic marker 156 on the medial malleollus in reason of the crank proximity), shoulder and hip joint centers were 157 located using the SCoRE method (Ehrig et al., 2006). For this method, a preliminary recording 158 159 asking the participants to repeat flexion-extension, abduction-adduction and circumduction of the 160 tested joint allowed the localization of their centers-of-rotation (Begon et al., 2007). Body segments 161 masses, center-of-mass positions, and radii of gyration were defined in accordance with De Leva's anthropometric charts (de Leva, 1996). All kinetics and kinematics data were recorded in three-162 dimensions. 163

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2.4. Data reduction and analysis

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167 Kinetics and kinematics data were synchronized using Nexus 1.7.1 system (VICON, Oxford,
 168 United-Kingdom) and filtered using a 4<sup>th</sup> order, zero phase-shift, low-pass Butterworth with a 8 Hz

169 cutoff frequency (McDaniel et al., 2014). In order to determine the factors affecting the saddle 170 vertical force, the trunk was represented (comprising the head and the pelvis) as being submitted to 171 external forces applied on the shoulders, hips, and saddle contact. The following equality has been 172 computed by isolating the head and trunk solid according to Newton's second law:

173

174 
$$F_s = m_t a_t - (W_t + F_h + F_{sh})$$
 (Equation 1)

175

176 where m<sub>t</sub> is the mass of the head and trunk solid according to De Leva's anthropometric chart, at is the linear acceleration of the head and trunk center-of-mass, Wt is the sum of the head 177 178 and trunk weights, F<sub>s</sub> is the saddle reaction force obtained from the saddle tube sensor, F<sub>sh</sub> is the shoulder reaction force calculated by inverse dynamics method from the handlebar sensors, and Fh 179 180 the hip reaction force calculated by inverse dynamics method from the pedal sensors. To compute F<sub>h</sub> and F<sub>sh</sub>, a classic inverse dynamic process was used (Winter, 1990). In this method, body-181 182 segments from upper and lower limbs were considered rigid and interconnected by frictionless 183 joints and their inertial parameters were derived from the scaling equations (de Leva, 1996). Given 184 the aims of the study, only the vertical components in Equation 1 were considered. This model is illustrated in Figure 3. The entire data processing was performed using custom-made codes written 185 186 in Scilab 5.4.0 (SCILAB, Scilab Enterprises). All the data were normalized to the subject's body 187 mass. During the crank cycle corresponding to the minimum saddle vertical force observed among the 10 s of recording for each power output, vertical forces presented in Equation 1 were extracted. 188 In this crank cycle and at the instant corresponding to the minimum saddle vertical force, vertical 189 190 force values were retained for further analyses.

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PLEASE INSERT FIGURE 3

*2.5. Statistics* 

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196 Before each statistical test, data normality and variance homogeneity were assessed using 197 Shapiro-Wilk's, and Levene's tests, respectively. A one-way repeated measures ANOVA (power output = 20, 40, 60, 80, 100 and 120% of sit-stand transition power) was performed to compare 198 199 saddle force levels across Power outputs. Post-hoc analyses were performed using Bonferroni's 200 method. To check the accuracy of the experimental model represented by the equality computed in 201 Equation 1, the difference between saddle vertical reaction force and the equivalent sum of forces 202 was quantified for each power output condition using the root-mean-square error (RMSE). In 203 addition, Pearson's coefficients (R) were used to determine the correlation between the two 204 patterns. Partial eta-squared  $(n^2)$  was used to quantify the size of the effect of power output on 205 vertical forces. All statistical analyses were performed using STATISTICA (STATSOFT, Maisons-206 Alfort, France). A p-value of 0.05 was defined as the level of statistical significance.

207

# **3. Results**

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The sit-stand transition power reached during a pedalling phase of 20 s at 90 RPM (i.e. during the first test, see methods) was  $568 \pm 93W$  ( $8.0 \pm 1.4 \text{ W.kg}^{-1}$ ) and the power outputs corresponding to 20, 40, 60, 80, 100 and 120% of sit-stand transition power were  $114 \pm 19 \text{ W}$ ( $1.6 \pm 0.3 \text{ W.kg}^{-1}$ ),  $227 \pm 37 \text{ W}$  ( $3.2 \pm 0.5 \text{ W.kg}^{-1}$ ),  $341 \pm 56 \text{ W}$  ( $4.8 \pm 0.8 \text{ W.kg}^{-1}$ ),  $454 \pm 74 \text{ W}$ ( $6.4 \pm 1.1 \text{ W.kg}^{-1}$ ),  $568 \pm 93W$  ( $8.0 \pm 1.4 \text{ W.kg}^{-1}$ ) and  $682 \pm 111W$  ( $9.6 \pm 1.6 \text{ W.kg}^{-1}$ ), respectively.

215 The static vertical force on the saddle (0% of sit-stand transition power) was  $5.30 \pm 0.50$ 216 N.kg<sup>-1</sup>.

217 Descriptive statistics about saddle vertical force are shown in Table 1. A significant main 218 effect (p < 0.001) of power output was found, showing that the magnitudes of minimum saddle

vertical force decreased significantly between each power output condition.
PLEASE INSERT TABLE 1
Accuracy of the model was assessed and the results of the saddle vertical force pattern
reconstruction using the equality described in Equation 1 are presented in Table 2. An illustration of
this reconstruction is presented in Figure 4.
PLEASE INSERT TABLE 2
PLEASE INSERT FIGURE 4
Vertical saddle, trunk inertial force, shoulders and hips reaction force patterns are presented
in Figure 5.
PLEASE INSERT FIGURE 5
The variation with power output of each term detailed in Equation 1 at the instantaneous
minimum saddle vertical force in the cycle is presented in Figure 6.
PLEASE INSERT FIGURE 6
4. Discussion

243 The primary purpose of this investigation was to test the hypothesis that the saddle vertical forces would decrease with increasing power output. Our findings supported our hypothesis with a 244 linear decrease of 87.4% of the saddle vertical reaction force, from  $5.30 \pm 0.50$  N.kg<sup>-1</sup> to  $0.68 \pm 0.49$ 245 N.kg<sup>-1</sup>, between a static position on the bicycle and the minimum instantaneous value obtained 246 while pedaling at 120% of the sit-stand transition power (Table 1). Another purpose of the study 247 248 was to determine the forces applied on the trunk during cycling at different pedal reaction forces in 249 order to interpret the decrease in saddle vertical force. The model presented in Equation 1 provided 250 an accurate examination of the forces associated with the saddle vertical force (Table 2 and Figure 251 4). These data suggest that the vertical saddle force decreased mainly in response to the increase in 252 hip vertical reaction forces (Figures 5 and 6). Consequently, with increasing pedal reaction forces, the body weight was less and less supported by the saddle. The results indicated that when the 253 saddle force approached 1 N.kg<sup>-1</sup>, the participants tended to spontaneously transit to the STAND 254 255 position, suggesting that the saddle force could be a predictor of the sit-stand transition power.

256 A combination of several strategies was observed to limit the decrease in saddle vertical 257 force in response to the increasing demand in pedal force, potentially increasing both the sit-stand transition power and the delay before the occurrence of the sit-stand transition. These strategies are 258 259 likely to help maintaining the SEAT position when high level of pedal reaction forces are created 260 and may also explain why the saddle vertical force did not reach zero (Figure 6). However, these 261 strategies have been previously reported as particularly metabolically costly (Korff et al., 2007; 262 Edwards et al., 2009; McDaniel et al., 2005). The first strategy observed was to pull on the pedal to 263 create downward reaction forces at the hip level (Figure 5). This pedal pulling may be associated 264 with the advantage of increasing the mechanical effectiveness of pedaling (Korff et al. 2007), and 265 explains the non-linear increase in the sum of pedal vertical forces during with increasing crank 266 power (Figure 6). However, and probably because human's lower limb is far stronger to produce force in extension than in flexion (Anderson et al., 2007), increasing the mechanical effectiveness 267

268 by training cyclists to pull more on the pedals has been reported to decrease their metabolic efficiency (Korff et al., 2007; Edwards et al., 2009). Because experts in cycling have been reported 269 to push more on the pedals at equivalent power output (Coyle et al., 1991) it could be expected that 270 271 they would have to create downward forces by pulling their handlebars and/or pedals and/or 272 accelerating their trunk downward simultaneously to the decrease in vertical saddle force at lower power outputs than the non-cyclists from our study, and more frequently in their daily practice 273 274 because of the higher power output that they develop. Further investigations are needed to confirm 275 this hypothesis which could lead to improvement in cycling performance. A second strategy 276 observed to limit the reduction of the saddle vertical force was to accelerate the trunk's center-of-277 mass downward (Figure 5). It is worth noting that the pattern of these accelerations are 278 synchronized with the pattern of saddle vertical force from 100% of the sit-stand transition power: 279 when the saddle force was at its minimum, the trunk's center-of-mass was accelerated downward, 280 and reciprocally, the upward acceleration of the trunk's center-of-mass occurred while the saddle 281 vertical force was at its maximum, the whole occurring twice by pedaling cycle. A third strategy 282 was to create a downward reaction force at the shoulders by pulling on the handlebar, this last strategy was mainly observed above the sit-stand transition power (Figure 6). Both of these 283 284 strategies involve additional muscular efforts from the upper limbs. As highlighted by McDaniel et 285 al. (2005), the upper limbs' metabolic cost is important in cycling. These authors showed that the use of a modified saddle allowing the stabilization of the trunk and a potential decrease in upper 286 limb muscular efforts decreased the metabolic cost of pedaling for a fixed power output. The 287 288 reductions were of 1.6, 1.2, and 0.2% at 40, 60, and 80 RPM, respectively and they showed that the best improvement in metabolic cost was obtained at the highest level of pedal forces (for a fixed 289 290 power output), i.e. in the conditions corresponding to the highest handlebars and pedals pulling and 291 trunk inertial forces observed in our study. The present data are in agreement with the interpretation 292 that with increasing pedal forces, the body weight was less and less supported by the saddle, and

293 that downward forces acting on the trunk were required to maintain the SEAT position above one level of crank power (for a given pedaling cadence of 90 RPM). The fact that costly strategies to 294 295 counteract the elevation of the trunk emerged at the power at which the participants spontaneously 296 switched to the STAND position suggests that this position could have been chosen in order to avoid these strategies. It is worth mentioning that several other factors may influence the choice of 297 298 the cycling position in the field such as aerodynamics (Debraux et al., 2011; Millet et al., 2014), or 299 slope gradient (Bertucci et al., 2005; Duc et al., 2008). However, the difficulty to keep force on the 300 saddle during high pedal reaction force production observed in this study is making the SEAT 301 position less attractive in these conditions, giving a mechanical reason to trigger the sit-stand 302 transition. Our study is the first to present saddle force patterns at different levels of pedal reaction force as a justification to trigger the sit-stand transition, and to explain these patterns by a 303 304 mechanical decomposition of the forces applied on the trunk during cycling. In order to further 305 confirm the present results, experimental designs manipulating the body weight, and/or testing 306 pedaling cadence effects on the magnitude of saddle vertical force and the occurrence of the sit-307 stand transition are warranted. Additionally, Hansen and Waldeland (2008) implemented repeated 308 cycling bouts to exhaustion with experimented cyclists and reported smaller sit-stand transition 309 power output than the one observed in this study with non-cyclists. This difference illustrates a 310 potential protocol-dependence of the sit-stand transition power, which may therefore also be 311 affected by the duration of the cycling trial. Altogether, further investigations on the sit-stand transition paradigm in cycling may lead to improvements in pedaling efficiency by potentially 312 313 decreasing the mechanical cost of pedaling in SEAT position at high pedal reaction forces, and by determining the precise pedal reaction force level at which the sit-stand transition is necessary to 314 maximize performance for different cadences, weights and durations conditions. 315

316 By determining the parameters involved in saddle force patterns, the present study also have 317 implication for clinicians, researchers, and manufacturers trying to understand the etiology of groin injuries and erectile dysfunction associated with cycling (Bressel et al., 2010; Bressel and Larson, 2003; Carpes et al., 2009; Lowe et al., 2004). Indeed, the inconsistency of the patterns of saddle force observed previously (Bolourchi and Hull, 1985; Stone and Hull, 1995; Wilson and Bush, 2007) can be explained by the different pedaling conditions used in these studies. Due to the sensitiveness of saddle forces (and thus saddle pressures) to pedal reaction forces, cyclists suffering from these pathologies should decrease their pedaling cadence for the same workload, as this is supposed to increase hip upward reaction force in order to decrease the saddle reaction force.

It is important to note some limitations of the present study. The use of a cycling ergometer is a common practice for testing, rehabilitation and training, but it differs with cycling in the field (Bertucci et al., 2012). Likewise, the potential protocol-dependence of the spontaneous sit-stand transition power determination needs further investigations.

329

# 330 Conclusion

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332 The body weight is gradually less supported by the saddle as pedal reaction forces increase, thus 333 decreasing the mechanical advantage of pedaling in the SEAT position. Strategies counteracting the 334 upward vertical pedal forces were observed around the power corresponding to the sit-stand 335 transition, suggesting that the spontaneous choice to rise in the STAND position may be a solution 336 to reduce the need to overcome these constraints. The spontaneous sit-stand transition occurred at minimum saddle vertical force about 1 N.kg<sup>-1</sup>; the high linearity of the relationship between saddle 337 338 vertical force and power output for a given cadence suggesting an ability of prediction of the sit-339 stand transition.

340

# 341 Acknowledgements

342	
343	Antony Costes was funded by a PhD grant from the French Ministry of Education and Research
344	(Ministère de l'Education et de la Recherche). The authors would like to thank Dr. Laurent Seitz for
345	his review of the manuscript.
346	
347	Conflict of Interest
348	
349	The authors have no financial or personal relationships with other people or organizations that could

350 have inappropriately influenced this research.

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FIGURE 1 – Experimental protocol to determine the sit-1 to-stand transition power (SSTP).
SSTP was considered as the CPO at which the participants rose from the saddle during at least 10 s.
FIGURE 2 – 3D force and moment sensors. A. Pedal. B. Saddle Tube. C. Handlebars.

488

489 **FIGURE 3 – Theoretical model of the cyclist. For clarity only one side of the body is** 

490 represented. Red arrows represent external forces (saddle, pedals and handlebars), and

491 dashed red arrows represent reaction forces applied on the trunk at the hip and shoulder

492 levels calculated by inverse dynamics. Only the vertical components of these forces are

493 represented. White dots represent kinematic markers. Black dots represent joint centers

494 calculated using the SCoRE method.495

FIGURE 4 – Illustration of the mean saddle vertical reaction force and mean sum of forces
applied on the trunk (presented in Equation 1) patterns for all participants (n = 25) for CPO
= 20% of SSTP.

499

500 FIGURE 5 – Vertical reaction force patterns presented along the crank cycle corresponding

501 to the minimum saddle vertical reaction force recorded for each CPO. Mean lefts (red line)

502 and rights (blue line) are presented ± one standard deviation. Data normalized by body-mass.

A. Saddle. B. Mass time acceleration of the trunk's center-of-mass. C. Shoulders. D.
 Hips.

504 505

506 **FIGURE 6 – Evolution of the vertical reaction forces across CPOs. Diamonds: saddle vertical** 507 **reaction forces. Squares: product between the mass of the trunk and the acceleration of its** 

508 center of mass. Triangles: sum of the two hip vertical reaction forces. White circles: sum of

509 the two shoulder vertical reaction forces. Black dots: weight of the 26 head and trunk. Each

510 data point corresponds to the instantaneous vertical force observed while the saddle vertical

511 force was minimal. Positive values indicate upward reaction forces (except for the trunk's

- 512 weight, reverted in a purpose of readability).
- 513 30

514 TABLE 1 – Minimum saddle vertical reaction forces across CPOs. Data are expressed in

515 N.kg- as mean ± standard deviation [range]. \*: Main CPO effect.a,b,c,d,e, and f represent

516 significant differences compared to 20, 40, 60, 80, 100, and 120% of SSTP conditions,

- 517 respectively (p < 0.001).
- 518

519 **TABLE 2 – Accuracy of the mechanical decomposition. Root-Mean-Square-Error (RMSE)** 

520 expressed in N.kg-1, and coefficients of correlation (R) between the pattern of vertical saddle

521 force and the pattern of the sum of forces applied on the trunk (terms described in Equation

522 1) are presented as MEAN (± SD). \* represents significant coefficient of correlation

523 40 (**P** < **0.001**).









537 538

FIGURE 5



FIGURE 6