PEDAL FORCE ASYMMETRIES AND PERFORMANCE DURING A 20-KM CYCLING TIME TRIAL

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Abstract:

It is unclear if applying larger or more symmetrical pedal forces leads to better performance in cycling. The aims of this study were to assess the relationship between pedal force production and performance in a cycling time trial and to evaluate the relationship between asymmetries in pedal force production and performance. Fifteen competitive cyclists/triathletes performed a 20 km cycling time trial on a cycle trainer while bilateral forces applied to the pedals were recorded along with total time. Total forces applied to the pedals were computed and converted into dominant and non-dominant forces using a leg preference inventory. Pedal force asymmetries ranged from 43% (in favour of the dominant limb) to 34% (in favour of the non-dominant limb). The relationship between total pedal force (averaged from both pedals) and performance time was small (r=-.32, effect size=.66) as well as the association between the asymmetry indices and performance time (r=.01, effect size=.06). In conclusion, applying large forces on the pedals and balancing pedal force application between the dominant and non-dominant limbs did not lead to better performance in this cycling time trial.

Key words: *left/right asymmetry, Waterloo Footedness Questionnaire, pedalling technique, power output, pedalling cadence*

Introduction

Studies have observed that a range from 40-60% of the force applied to the pedal is converted into crank torque (Bini, Hume, & Kilding, 2014; Mornieux, Stapelfeldt, Gollhofer, & Belli, 2008). Indeed, by converting a larger portion of pedal forces into crank torque, cyclists could enhance power output due to the need for lower force application on the pedals per pedal stroke (Bohm, Siebert, & Walsh, 2008). In contrast, Lanferdini et al. (2014) have shown that cyclists with a larger power output at their anaerobic threshold rely on applying larger pedal forces, but do not show improved pedalling technique. This finding is in agreement with the previous report from Coyle et al. (1991) showing that large force production at the power stroke is indeed critical to time trial cycling performance. However, none of these studies assessed the relationship between pedal force application and performance of cyclists during time trials. This information is important given that, during a cycling time trial, pacing should be optimized by tuning muscle activations and force production in order to postpone fatigue (Bini, Carpes, Diefenthaeler, Mota, & Guimarães, 2008; Tucker, et al., 2006). Therefore, improved cycling performance during a time trial should be associated to a larger pedal force production and not to an increased focus in pulling up the pedals at the crank cycle recovery phase (Korff, Romer, Mayhew, & Martin, 2007). However, to date, no study assessed if cyclists that apply large pedal forces present better performance than those who apply less force on the pedals.

Existing commercial power meters have recently enabled cyclists to monitor bilateral power production (e.g. Look-Polar®). This novel information on bilateral asymmetries in power production is aligned to evidence that cyclists present an imbalance in bilateral force production from 5-20% (Carpes, Mota, & Faria, 2010). More recent data indicated that asymmetries could be larger in uninjured cyclists (i.e. >60%) than the referred range of 5-20% (Bertucci, Arfaoui, & Polidori, 2012; Bini & Hume, 2014) which could anticipate a risk factor for overuse injuries via an overload of one leg compared to the contralateral leg. In this regard, it is unclear if cyclists with larger pedal force asymmetries could be limited in terms of performance compared to the cyclists whose pedal force production is more symmetrical. Moreover, the potential link between reduced asymmetries and better performance in cycling is warranted by the cycling community, which has discussed this issue at the Wattage Google Groups forum (Wattage, 2015) in order to decide whether asymmetries should be reduced by training to improve cycling performance. To date, one study assessing the link between bilateral asymmetries in cycling and performance was limited to the assessment of only six cyclists while measuring peak crank torque (incomplete range of force production) using an unreliable instrument (Carpes, Rossato, Faria, & Mota, 2007). The second study (Bini & Hume, 2015) was limited to very short duration time trials (i.e. 4 km) which does not provide information on longer duration tests. Therefore, there is a need to assess if pedalling, during longer duration trials, could enable cyclists to largely deviate from pedal force production symmetry, which could be observed due to the lower exercise intensity (Carpes, et al., 2007) and larger possibility to change muscle recruitment strategies.

In order to address the aforementioned questions, the goals of this study were to: 1) assess the relationship between pedal force production and performance in a 20 km cycling time trial and; 2) evaluate the relationship between asymmetries in pedal force production and performance in a cycling time trial. Our first hypothesis was that cyclists with better performance would produce larger pedal force because performance in cycling is related to larger pedal force application (see Lanferdini et al., 2014, for details). The second hypothesis was that increased pedal force production asymmetries would be associated with better performance because recent evidence showed that pedalling at larger loads leads to increased asymmetries (see Bini & Hume, 2014, for details).

Methods

Participants

Fifteen athletes with competitive experience in cycling (eleven, including eight males and three females) and triathlon (four, including three males and one female) with (mean±SD) 37±12 years of age, 71±13 kg of body mass and 177±11 cm of standing body height participated in the study. At the time of the evaluation sessions, cyclists/triathletes covered 331±80 km/week of cycling training in 5±1 sessions per week. Although their annual training volume was greater than 17,000 km, we ranked them as club riders (following descriptions from Ansley & Cangley, 2009) because their projected performance at the 16 km under the 20 km time trial test was greater than 22 minutes (see later details). Cyclists/triathletes did not report any injury or pain during racing or training over the last six months.

Before the start of the evaluation session, all procedures were presented to the participants who gave written informed consent to participate in the study which was approved by the Ethics Committee of Human Research where the study was conducted (CAEE: 09757612.1.0000.5347).

Data collection

Cyclists/triathletes completed the *Waterloo Footedness Questionnaire* to allow the determination of lower limb dominance (Elias, Bryden, & Bulman-Fleming, 1998). Briefly, the inventory involves twelve questions linking lower limb preference to tasks usually performed in daily activities (e.g. *If you had to hop on one foot, which foot would you use?*). Cyclists/triathletes were then asked to rate their preference for right or left leg use in these tasks.

Before testing, pressure of each bicycle rear wheel was calibrated according to manufacturer's instructions (~100 psi). Cyclists/triathletes warmed up for 10 minutes at self-selected workload and pedalling cadence ascertaining for moderate to low subjective effort. Laboratory temperature (26-28°) and humidity (~50%) were controlled throughout the testing period to minimize temperature effects on bicycle tire pressure and power output measurements (Davison, Corbett, & Ansley, 2009).

Cyclists/triathletes used their own bicycles attached to a cycle trainer (Cateye CS1000, Cateye Co., Osaka, Japan). The cycle trainer has a magnetic braking system that provides resistance proportional to the rear wheel speed (therefore, sensitive to gear ratio and pedalling cadence). After the warm-up, cyclists/triathletes performed a 20 km cycling time trial on the cycle trainer (Sporer & McKenzie, 2007; Zavorsky, et al., 2007). During the time trial, they were instructed to complete the 20 km time trial as fast as possible using self-selected strategies for gear-ratio and pedalling cadence. Elapsed time and power output were manually recorded at 5, 10, 15 and 19 km from the cycle trainer head unit while the force applied to the pedals was recorded using a pair of strain gauge instrumented pedals (Candotti, et al., 2007) and a reed-switch attached to the bicycle frame detected crank position. The pedal force system enabled normal and anterior-posterior force measurements using strain gauges with cyclists/triathletes using cycling shoes with Look® Delta cleats. As described elsewhere (Bini & Hume, 2013), instrumented pedals were calibrated with static loads and presented biological (due to within subjects variability) and technical reliability (due to equipment errors of measurement) of 5% for peak pedal forces during incremented load cycling tests.

Pedal force data passed through an amplifier (MSC-A1, Entran-MSC6, UK) and, along with reed switch signals, were recorded using an analogue-to-digital board (USB-1608G, Measurement Computing Inc, Norton, USA) at 2.4 kHz per channel using a custom-made script in Matlab (Mathworks Inc, Natick, USA). Analogue data (force and reed switch trigger) were acquired for 30 seconds at the aforementioned distances of the 20km trial. Total time was then recorded when cyclists/triathletes covered the 20-km.

Data analyses

A reed switch attached to the bicycle frame detected the position of the crank in relation to the pedal revolution and enabled to separate pedal force data into every crank revolution. Normal and anterior-posterior force signals were smoothed using a zero lag Butterworth low-pass digital filter with a cut-off frequency of 10Hz. Resultant (total) force applied on the sagittal plane of the pedal surface was calculated as a vector sum of normal and anterior-posterior pedal forces for a full crank cycle. Peak total pedal force was averaged for each pedal of each cyclist/triathlete across five crank revolutions for each section (i.e. 5, 10, 15 and 19 km) of the 20 km time trial test. We used peak pedal force because this variable has better reliability than pedalling technique measures (e.g. index of effectiveness; Bini & Hume, 2013) and because it is strongly related to power output. Average pedalling cadence was computed from timing of the reed switch sensor (Bini, et al., 2008). All force data processing was conducted using a custom-made script in Matlab (Mathworks Inc, Natick, USA). After that, peak total pedal force was averaged for the entire trial, for each cyclist/triathlete, for further analyses. The asymmetry index (AI%) was calculated as outlined by Robinson et al. (1987) for average total pedal force from the entire trial, defining positive asymmetry whenever the dominant limb (D) presented larger force measures than the non-dominant limb (ND):

$$AI\% = \left[\frac{D - ND}{(D + ND)/2}\right] \times 100$$

Statistical analyses

Right and left measures of total pedal force were converted into measures for dominant and non-dominant limbs using results from the *Waterloo Footedness Questionnaire*. Briefly, responses for the twelve questions in the inventory were converted into percentages of preference. Dominance was then defined whenever there was more than 60% of preference for a given limb. After that, Student's *t*-tests were conducted (assuming heteroscedasticity in data distribution) for the comparison of dominant to non-dominant total pedal forces, in addition to Cohen's effect sizes to measure the magnitude of changes (Hopkins, Marshall, Batterham, & Hanin, 2009). Significant differences were assumed when $p<.05$ and $ES>0.8$, to ascertain non-overlap in mean scores greater than 47% (Cohen, 1988).

In order to assess the relationship between performance time (i.e. total time to cover 20 km, in seconds) and total pedal forces, dominant and non-dominant pedal force data were averaged. In addition, the relationship between absolute values of pedal force asymmetry indices (non-negative results) and performance time was assessed using Pearson correlation coefficients, which were ranked following methods from Dancey and Reidy (2004), where $r=1.0$ indicates perfect association, r between .7 and .99 indicates strong association, r between .4 and .69 indicates moderate association and r smaller than .39 indicates small to no association. Effect sizes for correlation coefficients and p-values were computed, assuming a significant relationship when $p<.05$. All statistical analyses were conducted using custom-made spreadsheets (Excel, Microsoft, Inc., USA).

Results

One cyclist and one triathlete reported left leg preference (13%) at the *Waterloo Footedness Questionnaire*, while the others presented right leg preference. Cyclists/triathletes covered the 20 km time trial in 1,802±219 s (30±3.7 minutes) with average power output recorded from the cycle trainer of 294±72 W. Mean results for total pedal force, power output and pedalling cadence are depicted in Figure 1.

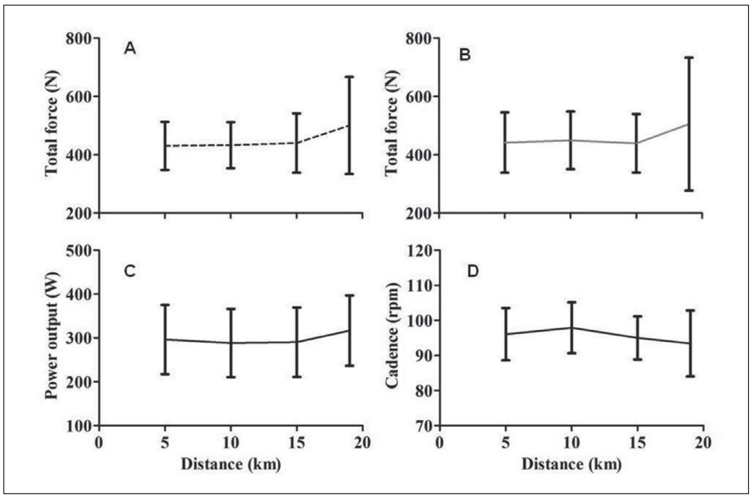

Figure 1. Grouped data (mean±SD) for total pedal force for the dominant (A) and non-dominant limbs (B), power output (C) and pedalling cadence (D) for the 15 cyclists/triathletes.

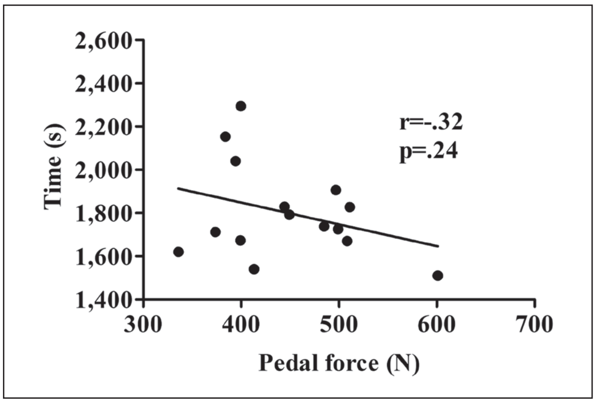

Figure 2. Relationship between total pedal force (average from dominant and non-dominant limbs) and performance time for the 15 cyclists/triathletes.

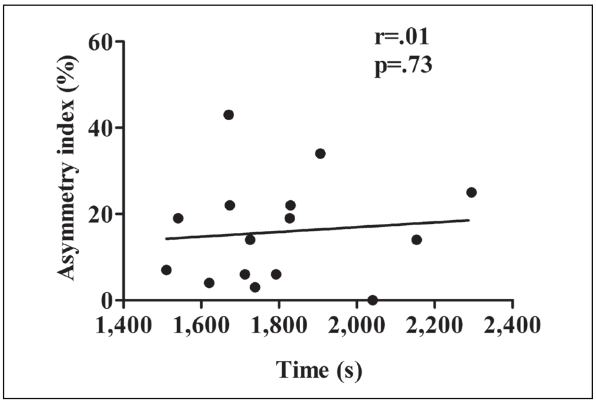

Figure 3. Relationship between absolute values of asymmetry indices (average from a 20 km time trial for dominant and non-dominant limbs) and performance time for the 15 cyclists/triathletes.

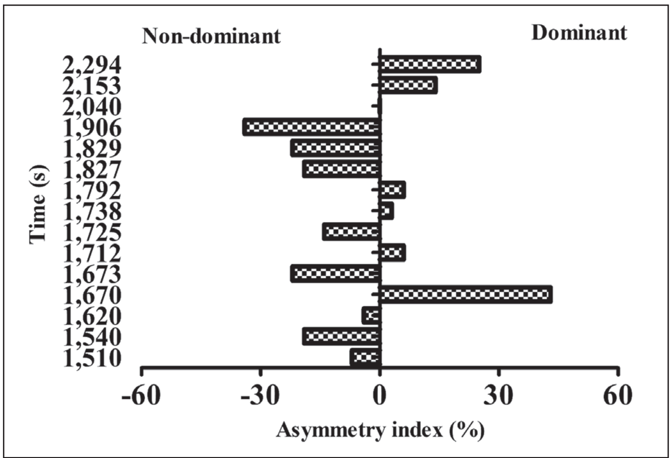

Figure 4. Individual asymmetry indices for total pedal force for the 15 cyclists/triathletes taken as averages from the 20 km time trial.

Peak total pedal force from the dominant limb at the 20 km time trial was 418±64 N whilst the non-dominant limb recorded 475±92 N, which were not significantly different (p=.06 and ES=0.73). Asymmetry index ranged from 43% (in favour of the dominant limb) to 34% (in favour of the non-dominant limb) with averages of -3±20%.

The relationship between total pedal force (averaged from both pedals) and performance time was small (r=-.32, p=.24, ES=0.66 – see Figure 2) whilst the association between absolute asymmetry indices and performance time was also small (r=.01, p=.73, ES=0.06 – see Figures 3 and 4).

Individual asymmetry indices varied largely when associated to performance time for the fifteen cyclists/triathletes, suggesting that large asymmetries are not accompanied by reduced performance time (see Figure 4).

Discussion and conclusions

This study assessed the relationship between pedal forces and performance in a 20 km cycling time trial along with the relationship between bilateral asymmetries in pedal forces and performance of cyclists/triathletes. The main findings were that larger pedal force application did not lead to better performance for the evaluated cyclists/triathletes and bilateral asymmetries were not associated to performance. These findings are novel because recent studies observed that greater total pedal forces were somewhat linked to larger power output at the anaerobic threshold (Lanferdini, et al., 2014). In parallel, only one study observed a weak link between large total pedal force production and better performance, and a weak link between asymmetries in pedal force and short duration time trial (i.e. 4 km) cycling performance (Bini & Hume, 2015). These results were confirmed by our data assessing a longer duration trial in the present study. The main difference from the current study in relation to the article by Bini and Hume (2015) is that we assessed a longer duration trial. This is critical because, during a longer cycling training, athletes are challenged to optimize their pacing strategies in order to maximize performance. Indeed, during a 4 km time trial (as performed in the research by Bini & Hume, 2015) cyclists pedalled very close to their VO_{2max}, which limits any room for selecting different muscle strategies, enforcing maximal pedal force application. On the other hand, during a 20 km time trial, we could observe that cyclists were capable to increase pedal forces close to the end of the trial ("end spurt" – as shown previously by Tucker, et al. 2006).

To enhance performance, cyclists are commonly instructed to apply the largest possible forces at the crank cycle power stroke phase compared to circling or pulling up the pedals at the recovery phase (Korff, et al., 2007). For cyclists/triathletes assessed in the present study, the largest peak total force application on the pedals did not lead to better performance. A reason could be that pedal force should be driven properly (i.e. perpendicular to the crank-arm) in order to generate torque in favour of crank motion. Rossato, Bini, Carpes, Diefenthaeler, and Moro (2008) observed, via increases of 20% in pedalling cadence, that cyclists were able to significantly enhance their pedal force effectiveness. These authors stated that cyclists can optimize pedal force effectiveness by improving force directions during the power stroke when pedalling at faster cadences. Therefore, cyclists/triathletes should focus on driving larger pedal forces as close as possible to the 3 o'clock crank position (i.e. 90° of crank angle) in order to convert the greatest possible proportion of their pedal force into crank torque. An alternative could be to increase pedalling cadence in order to enhance inertial contribution to pedal forces for a given muscular contribution (Loras, Ettema, & Leirdal, 2009).

A qualitative assessment of average power output from our cyclists/triathletes indicates that most of these athletes opted for an *all out strategy* towards the end of the time trial, similarly to observations from previous studies (Bini, et al., 2008; Tucker, et al., 2006). This strategy was accomplished by either an increase in pedal forces linked to a decrease in pedalling cadence or vice versa. In our study, cyclists/triathletes had full control of their gear ratio (which affects pedal forces) and pedalling cadence in order to optimize their pacing strategy. Therefore, the combination between pedal force and cadence should affect power output and performance in time trials, which may have reduced the relationship between pedal force and performance time in our study. However, in a previous study, Bini et al. (2008) did not observe a relationship between pedalling cadence and cycling performance. Therefore, it is uncertain whether cyclists/triathletes should focus on increasing the power output by pedalling at higher cadences or by changing gears for a given cadence. Individual strategies should be assessed via sprint tests (Dorel, et al., 2010) which could provide an outline of the force-velocity properties for each cyclist/triathlete.

An inverse relationship between bilateral asymmetries in pedal forces and cycling performance could have been expected assuming that towards maximal exercise effort, inter-hemispheric cortical communication should be enhanced to provide full neural drive to lower limbs (Carpes, Mota, et al., 2010). However, both increases (Bini & Hume, 2014) and decreases (Carpes, et al., 2007) in bilateral asymmetries were observed towards maximal exercise effort. In the case of the 20 km time trial, exercise intensity is close to ~70% of maximal aerobic power output (Sporer & McKenzie, 2007) which does not induce maximal exercise effort. These findings indicate that asymmetries could be tuned and some cyclists/triathletes may opt for driving the pedals stronger using either their dominant or the non-dominant limb, as shown in Figure 3.

Evidence from muscle activation indicates that both the dominant and non-dominant limbs could present similar efficiencies during single leg cycling (Carpes, Diefenthaeler, et al., 2010). In contrast, larger mechanical load applied to the bones by the dominant limb during growth could lead to increases in bone enthesis (Kanchan, Mohan Kumar, Pradeep Kumar, & Yoganarasimha, 2008) and potential changes in muscle moment-arm. Similarly, recent findings indicate that differential load applied to the dominant lower limb could determine ~30% greater stiffness for the Achilles tendon (Bohm, Mersmann, Marzilger, Schroll, & Arampatzis, 2015). Taken together, it is uncertain if larger bilateral asymmetries are detrimental to performance or if they are a natural consequence from adaptation of musculoskeletal tissues to limb preference.

The most suggested range for normative asymmetries in cycling is between 5-20% of bilateral forces differences (Carpes, Mota, et al., 2010) for uninjured cyclists and up to 400% in injured cyclists (Hunt, Sanderson, Moffet, & Inglis, 2004; Mimmi, Pennacchi, & Frosini, 2004). Our cyclists/triathletes presented bilateral asymmetries in peak pedal forces up to 43%, which is similar to the observed in previous studies (Bertucci, et al., 2012; Bini & Hume, 2014), but larger than in other studies (Bini, Diefenthaeler, Carpes, & Mota, 2007; Garcia-Lopez, Diez-Leal, Larrazabal, & Ogueta-Alday, 2015). However, differences in variables used to compute bilateral asymmetries in cycling (i.e. crank torque, total pedal force, crank power) should be taken into account when comparing results from different studies. More research is needed to provide, perhaps, a wider band for normative asymmetries in uninjured cyclists/triathletes, which could indicate cyclist who should follow an intervention to reduce bilateral asymmetries in order to prevent overuse injuries (Carpes, Mota, et al., 2010).

Among the limitations of the present study, pedal and lower limb kinematics could have been measured in order to compute potential asymmetries in joint kinetics, which could have helped to assess any sources of asymmetries in pedal forces.

In summary, cyclists/triathletes that opted for applying large pedal force did not perform better than their counterparts. Larger bilateral asymmetries in pedal forces were apparently not detrimental to performance because some cyclists/triathletes with large asymmetries performed better than others with reduced asymmetries. Mean asymmetries were in a wider range (up to 43%) than normative for uninjured cyclists (5-20%), which could impose a need to revisit the normative ranges for asymmetries in cycling.

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Conflict of interest statement

The authors declare no existing conflict of interest for the contents of the article.