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BILATERAL ASYMMETRY ASSESSMENT IN CYCLING USING COMMERCIAL INSTRUMENTED CRANK SYSTEM AND INSTRUMENTED PEDALS

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ABSTRACT

The accuracy of commercial instrumented crank systems for symmetry assessment in cycling has not been fully explored. Therefore, our aims were 1) to compare peak crank torque between a commercial instrumented crank system and instrumented pedals and 2) to assess the effect of power output on bilateral asymmetries during cycling. Ten competitive cyclists performed an incremental cycling test to exhaustion. Forces and pedal angles were recorded using right and left instrumented pedals synchronized with crank torque measurements using an instrumented crank system. Differences in right (dominant) and left (non-dominant) peak torque and asymmetry index were assessed using effect sizes. In the 100-250 W power output range, the instrumented pedal system recorded larger peak torque (dominant 55-122%, non-dominant 23-99%) than the instrumented crank system. There was an increase in differences between dominant and non-dominant crank torque as power output increased using the instrumented crank system (7-33%) and the instrumented pedals (9-66%). Lower limb asymmetries in peak torque increased at higher power output levels in favour of the dominant leg. Limitations in design of the instrumented crank system may preclude the use of this system to assess peak crank torque symmetry.

Abstract count: 189

Introduction

Bilateral cycling motion has usually been assessed assuming symmetry in force production and kinematics of lower limbs. However, differences in power output, and mechanical work of the legs have ranged from 5% to 20% in uninjured cyclists and non-cyclists [1]. Conflicting results were reported comparing cyclists [2-4] and non-cyclists [5] without clear relationships between pedalling cadence [2] and power output level [5] in bilateral symmetry.

Peak torque at the propulsive phase of crank revolution (i.e. from 12 o'clock to 6 o'clock crank positions) has been reported as one of the most important predictors of performance during 40-km time trials [6] given a large percentage of the force applied to the pedal in the sagittal plane can be translated into crank torque in this part of crank revolution [7]. Therefore, cyclists should apply large crank torque on both cranks to enhance power output for a given pedalling cadence. Using peak torque as a measure of pedalling symmetry, authors have reported that differences between legs were significant at lower power output levels (≤90% of maximal oxygen uptake) and decreased at higher power output levels (i.e. >91% of VO_{2Peak}) for six competitive cyclists [3, 8]. In contrast, another study did not show significant differences in mean torque computed during full crank revolution for eleven cyclists at different power output levels (60-100% of maximal oxygen uptake) [4]. Therefore, it is unclear if crank torque symmetry is related to power output level. The potential reduction in asymmetries in torque at higher power output levels may be due to an increased bilateral neural input by inter-hemispheric cortical communication to facilitate the excitability of both legs [1].

Evaluation of bilateral asymmetry has gained popularity because some commercial devices provide right to left crank comparisons for torque and power output. One example is the SRM® torque analysis system which enables the user to assess peak crank torque from dominant and non-dominant lower limbs during cycling [9]. The SRM® power meter measures the deformation on the shafts of the crank set resulting from the torque applied on both cranks (i.e. net crank torque). However, a recent study showed that the measures of peak torque from the SRM® torque analysis system are only accurate for power output greater than 80% of maximal power output [10]. Therefore, separate measures of dominant and non-dominant crank torque are not accurate using this device because the torque at dominant and non-dominant cranks are computed as net torque (i.e. torque from the contralateral leg diminishes torque from the ipsilateral leg). Using the commercial instrumented crank systems (i.e. SRM® torque analysis system), it has been assumed that peak torque observed during the propulsive phase of crank revolution are exclusively affected by the ipsilateral leg [3], which may not be completely valid. Consequently, the accuracy of bilateral symmetry assessment using instrumented crank systems may be compromised by the design of this device. Instrumented pedals have been able to provide crank torque measurements independently for dominant and non-dominant legs [11], which are expected to offer a more accurate measure of peak crank torque than instrumented crank systems. Therefore there is uncertainty on the accuracy of asymmetries in bilateral peak torque taken from instrumented crank systems (i.e. SRM® torque analysis system). There is also need to assess if potential differences in bilateral peak torque measurements taken from instrumented pedals and instrumented crank systems would be affected by changes in power output level.

Therefore, our aims were 1) to compare peak crank torque between a commercial instrumented crank system and instrumented pedals and 2) to assess the effect of power output level in bilateral asymmetries during cycling. Our hypotheses were that the instrumented crank system should underestimate bilateral asymmetries and that asymmetries should be diminished at higher power output levels.

Methods

Participants

Ten cyclists (three female and seven male club riders) with competitive experience in cycling and/or triathlon were invited to participate in the study: age = 30 ±7 years, body mass = 72.8 ±13 kg, standing height = 175 ±12 cm, maximal oxygen uptake 55.6 ±8.8 ml/kg/min, peak power output = 336 ±77 W, and peak power per body mass = 4.6 ±6 W/kg). Lower limb dominance assessed by the Waterloo inventory indicated all ten cyclists were right leg dominant. The Ethics Committee of AUT University approved the research protocol (AUTEC 10/56).

Design

A quantitative repeated measures experimental design was used to collect data (cross-sectional).

Data collection

Force components (normal and anterior-posterior) from a 2D pedal dynamometer custom developed for Look® type cleats [12, 13] were computed using the regression between three static load points (0 kg, 5 kg and 10 kg) applied to the pedals and voltage output when R^2 was greater than 0.99. Mechanical coupling between anterior-posterior and normal loads were corrected using a gain matrix [14]. Potentiometers attached to the pedal spindle (Vishay Spectrol model 357, Vishay Intertechnology, Malver, USA) were calibrated using a manual goniometer (Physio-Med Services, model 30 cm, Patterson Medical Ltd, Nottinghamshire, UK) set at four crank-to-pedal axle angles (0°, 90°, 180° and 270°, taken twice for each crank-to-pedal angle) to compute the relationship between voltage output and the measured angle. The calibration factors were defined when differences in voltage taken from both trials were lower or equal to 1% for each given crank-to-pedal angle.

Body mass and height were measured according to International Society for the Advancement of Kinanthropometry protocols [15]. Cyclists' bicycle saddle height and horizontal position were measured to set-up the stationary cycle ergometer (Velotron, Racermate Inc, Seattle, USA). The cyclists performed an incremental cycling exercise on the cycle ergometer with three minutes of warm-up at 100 W and pedaling cadence visually controlled at 90 ±2 rpm. Power output was then increased to 150 W and remained increasing in a step profile of 25 W/min until cyclists' exhaustion [16]. A script was configured in the Velotron CS2008 software (Velotron, Racermate Inc, Seattle, USA) for automatic control of the cycle ergometer power output in a constant workload mode. This configuration enabled a constant power output with cycle ergometer resistance changing to balance for fluctuations in pedalling cadence. Gas exchanges were continuously sampled from a mixing chamber where samples were drawn into the oxygen and carbon dioxide analyzers for continuous measurement using a metabolic cart (TrueOne 2400, Parvo Medics, Salt Lake City, USA). Analyzers for oxygen and carbon dioxide were calibrated according to manufacturer recommendations. Maximal power output and maximal oxygen uptake were defined as the highest power output measured during the test and as the highest oxygen uptake value computed over a 15 s average of the data, respectively for assessment of cyclists' performance and fitness level. All aforementioned procedures served as familiarisation. After two to seven days, cyclists returned to the laboratory at the approximate same time of the day to perform the incremental test following the same procedures.

Normal and anterior-posterior forces were measured using a pair of strain gauge instrumented pedals [12], with pedal-to-crank angle measured using angular potentiometers attached to the pedal spindle. Pedal force signals passed through an amplifier (Signal conditioning unit, model RM-044, Applied Measurements, Mitcham, Australia) and, along with potentiometers, reed switch signals and SRM® torque analysis system signals (Schoberer Rad Meßtechnik, Jülich, Germany) were recorded using an analogue to digital board (PCI-MIO-16XE-50, National Instruments, Austin, USA) at 600 Hz per channel using a custom made script in Matlab (Mathworks Inc, Natick, USA). Analogue data were acquired between the 20th and the 40th s of each step of 50 W (i.e. 100 W, 150 W, 200 W, 250 W, etc).

Data analyses

Pedal-to-crank angle measured by the potentiometers were converted into sine and cosine to compute tangential and radial forces on the cranks. A low pass zero lag Butterworth digital filter with cut off frequency of 10 Hz was applied to the sine and cosine data from potentiometers to attenuate signal noise from the gap in potentiometer voltage readings [11]. Crank torque was measured by the pedals using the tangential force on the cranks and crank length, and by the SRM® torque analysis system, as per shown in Figure 1. A frequency to voltage conversion factor of 4 x 10^{-4} and frequency to torque factor gathered at the calibration trial were used to convert torque measurements from voltage to Nm.

*****Figure 1*****

A reed switch attached to the bicycle frame detected the position of the crank in relation to the pedal revolution and enabled separate pedal forces and torque data for every crank revolution and for the propulsive (i.e. from 12 o'clock to 6 o'clock crank positions) and recovery phases (i.e. from 6 o'clock to 12 o'clock crank positions) for right and left cranks. Peak crank torque of right (dominant) and left (non-dominant) cranks were determined when the crank was at the propulsive phase and at the recovery phase, respectively, using a clockwise motion of the crank as reference. Peak crank torque was averaged over five complete pedal revolutions for each crank on the instrumented pedals and the commercial instrumented crank system. Standard deviations for peak torque from dominant and non-dominant limbs were computed from five crank cycles to report intra-limb variability. Asymmetry index (AI%) was calculated as outlined by Robinson et al. [17], using measures from dominant (D) and non-dominant (ND) legs normalized by the average of dominant and non-dominant measures.

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

Statistical analyses

Errors of calibration of normal and anterior-posterior components and potentiometers of the pedals were computed as average percentage differences in voltage due to calibration load (or angle for potentiometer) in relation to the output voltage. As an example, for the normal force of the right pedal, the difference in voltage from 0 kg to 5 kg was 0.1547 V and the difference in voltage from 5 kg to 10 kg was 0.1544 V, resulting in 0.19% difference in voltage due to load application. Variation in pedalling cadence was computed by percentage differences across five crank revolutions.

Peak torque for dominant and non-dominant cranks and asymmetry index (mean and SD) were compared for instrumented pedals and the instrumented crank system. All variables were analyzed for the 100 W, 150 W, 200 W, 250 W, 300 W and 350 W power outputs of the incremental test. Normality of distribution and sphericity were confirmed for all variables via the Shapiro-Wilk and Mauchly tests, respectively, after application of a logarithmic transformation using SPSS for Windows 16.0 (SPSS, NY, USA).

Mean percentage differences between dominant and non-dominant peak torques and the asymmetry index from the instrumented crank system and the instrumented pedals were computed and comparisons were conducted using Cohen's effect sizes (ES). We used effect sizes opting for a threshold of large effects (ES = 1.0) for substantial changes. This is a more conservative approach than previously described [18], but it would ensure a non-overlapping in distribution of scores greater than 55% [19].

Results

Errors from calibration procedures were 0.19% and 0.68% for the normal force, and 0.68% and 0.56% for anterior-posterior force for the dominant and non-dominant pedals, respectively. Error in pedal-to-crank angle of each potentiometer was 0.5%. Mean variation in pedalling cadence between cyclists was 1% resulting in an estimated error from equipment of ~1.37% and ~1.74% for crank torque of the dominant and non-dominant pedals, respectively. For the instrumented cranks, errors in instrumented crank measurements followed reports from previous studies [20].

Greater peak torque was observed for dominant and non-dominant pedals than for instrumented crank system as shown in Figure 2 and Table 1.

*****Figure 2*****

In general, large differences for dominant (31-48%) and non-dominant (17-39%) peak crank torque between the commercial instrumented crank system and the instrumented pedals were observed at power output ranges of 100-250 W. At higher power outputs (300 W and 350 W) there were moderate to trivial differences in peak crank torque comparing dominant to non-dominant pedals. There was a trend for an increase in the difference between dominant and non-dominant crank torques using the commercial instrumented crank system (7-33%) and the instrumented pedals (9-66%), but large differences were only found for the instrumented pedals at power outputs higher than 200 W. The instrumented pedals presented larger asymmetry indices compared to the commercial instrumented crank system at 250 W (see Table 1). Intra-limb variability for peak crank torque from dominant and non-dominant limbs (4-11% - see Table 2) was smaller than differences between dominant and non-dominant peak torques for the instrumented crank system (5-33%) and for the instrumented pedals (9-66%).

*****Table 1*****

*****Table 2*****

Discussion

Our study compared dominant to non-dominant peak crank torque measured by a commercial instrumented crank system (i.e. SRM® torque analysis system) and instrumented pedals during bilateral cycling at varying power output levels. The reason for these comparisons was based on the increasing use of the instrumented crank system for the assessment of asymmetries in cycling [3, 8] and potentially because the commercial instrumented crank system may underestimate the peak crank torque and asymmetry analysis [10].

Lower peak torque was observed in this study for the commercial instrumented crank system compared to the instrumented pedals for the same power output level. Greater asymmetries were observed at higher power output levels but large differences between dominant and non-dominant crank torque were only observed using the instrumented pedals. The asymmetry index was greater than 20% (usually reported for uninjured cyclists [1]) for the commercial instrumented crank system only at 350 W and for the instrumented pedals at power outputs greater than 150 W. The primary reason for these differences between systems is related to the electronic characteristics of each system. The commercial instrumented crank system, as outlined in Figure 1, is designed to measure the deformation on the shafts of the crank set due to the torque applied on both cranks.

Using the example highlighted in Figure 1, if a cyclist applied 20 Nm of torque (clockwise) with the ipsilateral leg and 5 Nm of torque (anticlockwise) with the contralateral leg, the commercial instrumented crank system would record 15 Nm of torque. Therefore, the torque at dominant and non-dominant cranks is computed as a net torque (i.e. torque from the contralateral leg diminishes torque from the ipsilateral leg). Instrumented pedals measure the force on the pedal surface (e.g. normal and anterior-posterior components) and compute crank torque independently using pedal-to-crank angles [11]. This is a more accurate approach because forces from each leg are measured separately, reducing contralateral to ipsilateral effects on crank torque measures. Therefore, care should be taken if instrumented cranks are used for pedaling technique assessment due to possible interference in the data of each leg caused by the opposite leg, as previously conducted [21].

Intra-limb variability has been recently suggested to play a role on bilateral asymmetries in running [22]. However, intra-limb variability in peak torque (4-11%) was smaller in our study than differences between dominant to non-dominant peak torque (5-66%). Additional concern has been raised due to the use of the asymmetry index to identify bilateral differences in kinetic variables during dynamic tasks [22]. Large between-subjects variability in asymmetry indices (for instrumented crank system and the instrumented pedals) resulted in less pronounced effects sizes comparing instrumented cranks to pedals than using raw crank torque data. Reduced effect sizes for comparison between instrumented cranks and pedal asymmetry indices reinforce the limitation of asymmetry indices to detect bilateral differences in kinetic variables during cycling.

Higher power outputs resulted in greater bilateral differences assessed by instrumented pedals which are contrary to previous findings [3, 4, 8]. Cyclists were observed to reduce differences in peak torque at higher power outputs [3, 8], however, peak torque was measured using a instrumented crank system in these studies. Another study did not observe effects from power output level in full crank revolution average torque symmetry in cyclists using instrumented pedals [4]. Reductions in asymmetries in crank torque at higher power outputs have been hypothesized due to a potential increased bilateral neural input by inter-hemispheric cortical communication to facilitate the excitability of both legs [1]. However, studies assessing muscle activation in cyclists during bilateral cycling exercise at increasing power outputs did not report differences in lower limb muscle activation comparing both legs [23]. Muscle activation during single leg cycling did not differ when cyclists dominant and non-dominant legs were compared [24], which suggests that lower limb neural drive may not differ between legs. Substantial differences in cycling efficiency have not been observed in cyclists during single leg cycling, suggesting that contributions from independent legs to efficiency are similar [24]. Potential differences in joint motion[25] from bilateral asymmetries in bone dimensions could be a reason for observed asymmetries in pedalling kinetics. It may be the case that asymmetries are related to changes in bone dimensions due to asymmetrical load applied to the skeleton during bone growth[26]. Further research should shed light on why some cyclists present larger crank torque asymmetries than others and how this would impact their performance and injury risk.

Lower limb dominance may have played a role in increasing asymmetries at higher power outputs. Evidence suggests that the kicking dominant leg contributed significantly more to average crank power than the non-dominant leg [2], which is in line with our results. It has been previously showed that pedalling asymmetries are highly variable across different days of assessment and that asymmetries depend on exercise condition [2, 5]. Further research should assess bilateral muscle activation and joint kinetics in cyclists with similar levels of crank torque asymmetry to compute individual joint contributions to crank torque from right and left legs.

Some limitations may have affected the results of our study. Trials using single leg cycling could have been conducted to isolate the influence of the contralateral leg in torque readings from the instrumented crank system. During single leg cycling, torque measured by the instrumented crank system should not be affected by contralateral leg therefore crank torque measures would be isolated to the ipsilateral leg [27]. Although this approach is not ecologically optimal, it would shed light on the effects of contralateral resistive torque on the instrumented crank system data and would provide a practical use of the instrumented crank system for measurement of bilateral asymmetries. Combined fatigue and power output changes during the incremental test may have affected measures of peak torque and bilateral asymmetries. Randomizing power outputs would isolate for fatigue and work rate effects in crank torque asymmetries.

Practical applications

For coaches and cyclists, assessing bilateral asymmetries should be preferably conducted using instrumented pedals rather than instrumented crank systems at varying power output levels. The option for varying power output levels is due to the large ranges of work rates performed by cyclists and triathletes during racing [28, 29]. Also, using incremental power output test would be convenient to gather laboratorial measures (i.e. maximal oxygen uptake) along with bilateral lower limb force/torque measures.

Conclusions

Greater dominant to non-dominant differences in peak torque were observed using instrumented pedals compared to the instrumented crank system in power output ranges of 100-250W. Substantial differences in dominant to non-dominant peak torques could only be assessed using instrumented pedals, with increased asymmetry observed at higher power outputs in favour of the dominant leg. Commercial instrumented crank systems are thus not recommended to assess crank torque asymmetries during bilateral pedalling. Whenever possible, instrumented pedals should be used for torque and lower limb asymmetry assessments.

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Table captions

Table 1. Means ± standard deviations, mean percentage differences and effect sizes comparing both systems (commercial instrumented crank system and instrumented pedals) and differences between dominant (D) to non-dominant (ND) cranks for peak torque and asymmetry index.

Table 2. Mean (standard deviations) of crank torque for the six power outputs from the incremental test from 10 cyclists.

Figure captions

Figure 1. Image of the instrumented pedal attached to the instrumented crank system (A). Illustration of the locations of sensors for crank torque measurement for the instrumented crank system and instrumented pedals. Arrows indicate crank torque applied simultaneously by the ipsilateral and contralateral legs (B).

Figure 2. Crank torque measured by the pedals (dominant - A, non-dominant - B, and dominant + non-dominant - C) and by the instrumented crank system (D). Data from five consecutive revolutions of the ten cyclists at 200 W of workload and 90 rpm of pedalling cadence. Arrows indicate peak crank torque.

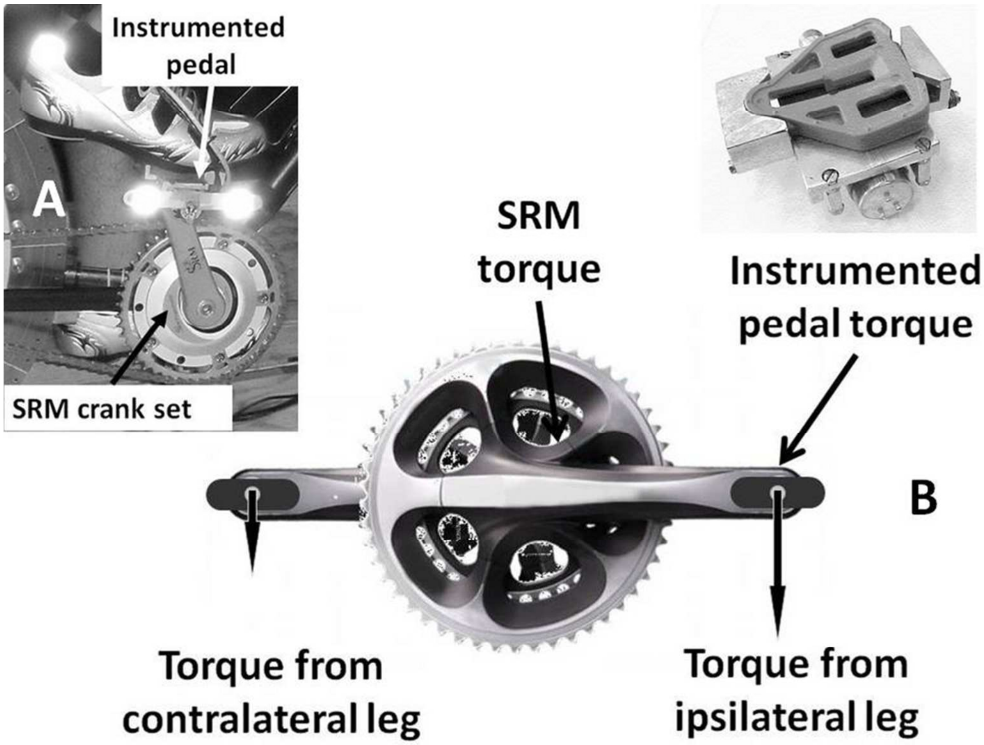
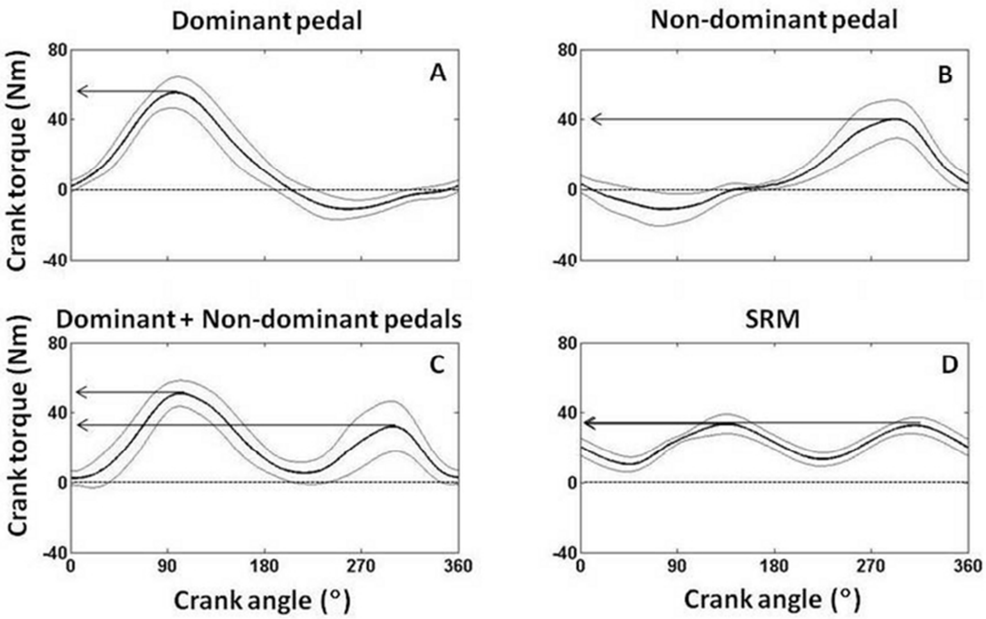


Figure 1. Image of the instrumented pedal attached to the instrumented crank system (A). Illustration of the locations of sensors for crank torque measurement for the instrumented crank system and instrumented pedals. Arrows indicate crank torque applied simultaneously by the ipsilateral and contralateral legs (B).
99x75mm (300 x 300 DPI)



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65x42mm (300 x 300 DPI)

Tables

Table 1. Means ± standard deviations, mean percentage differences and effect sizes comparing both systems (commercial instrumented crank system and instrumented pedals) and differences between dominant (D) to non-dominant (ND) cranks for peak torque and asymmetry index.

	Dominant peak torque (Nm)			Non-dominant peak torque (Nm)			Dominant vs. non-dominant peak torque		Asymmetry index (%)		
Power output level	Crank system	D-Pedal	Crank system vs. D-Pedal	Crank system	ND-Pedal	Crank system vs. ND-Pedal	Crank system	Pedals	Crank system	Pedals	Crank system vs. Pedals
100 W (n = 10)	17 ±6	33 ±5	48%; 3.0, L	18 ±8	30 ±9	39%; 1.4, L	7%; 0.2, T	9%; 0.4, S	6 ±17	11 ±28	280%; 0.8, M
150 W (n = 10)	23 ±8	41 ±6	43%; 2.4, L	22 ±7	34 ±10	35%; 1.4, L	5%; 0.1, T	19%; 0.8, M	4 ±15	20 ±33	418%; 0.7, M
200 W (n = 10)	31 ±11	48 ±7	36%; 2.0, L	28 ±8	39 ±8	27%; 1.3, L	10%; 0.3, S	26%; 1.3, L	8 ±17	22 ±30	181%; 0.6, S
250 W (n = 10)	39 ±14	56 ±8	31%; 1.6, L	36 ±9	43 ±12	17%; 0.7, M	8%; 0.3, S	29%; 1.3, L	5 ±15	28 ±31	428%; 1.0, L
300 W (n = 7)	53 ±19	65 ±8	19%; 0.9, M	45 ±11	46 ±12	1%; 0.1, T	17%; 0.5, M	42%; 1.9, L	13 ±20	36 ±33	189%; 0.9, M
350 W (n = 6)	73 ±25	75 ±7	3%; 0.1, T	55 ±18	46 ±14	21%; 0.6, M	33%; 0.8, M	66%; 2.8, L	27 ±18	51 ±36	93%; 0.9, M

Abbreviations used are for dominant (D-pedal) and non-dominant pedals (ND-pedal) and effect sizes of trivial (T), small (S), moderate (M) and large (L).

Table 2. Mean (standard deviations) of crank torque for the six power outputs from the incremental test from 10 cyclists.

Power output level	Peak torque – Nm	
	Dominant	Non-dominant
100 W (n = 10)	1.4 (4%)	2.2 (7%)
150 W (n = 10)	2.2 (5%)	1.8 (5%)
200 W (n = 10)	2.7 (6%)	2.2 (6%)
250 W (n = 10)	3.4 (6%)	3.2 (8%)
300 W (n = 7)	5.1 (8%)	3.2 (7%)
350 W (n = 6)	8.1 (11%)	3.7 (8%)

Standard deviation for peak torque from five crank cycles for dominant and non-dominant limbs.