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1 **Title:** Isovelocity vs Isoinertial Sprint Cycling Tests for Power- and Torque-Cadence

2 Relationships

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ABSTRACT

Sprint cycling performance is heavily dependent on mechanical peak power output (PPO) and the underlying power- and torque-cadence relationships. Other key indices of these relationships include maximum torque (T_{MAX}), cadence (C_{MAX}) and optimal cadence (C_{OPT}). Two common methods are used in the laboratory: isovelocity and isoinertial. Little research has been carried out to compare the magnitude and reliability of these performance measures with these two common sprint cycling assessments. The aim of this study was to compare the magnitude and reliability of PPO, T_{MAX} , C_{MAX} and C_{OPT} measured with isovelocity and isoinertial sprint cycling methods. Two experimental sessions required 20 trained cyclists to perform isoinertial sprints and then isovelocity sprints. For each method, power-cadence and torque-cadence relationships were established and PPO and C_{OPT} were interpolated and T_{MAX} and C_{MAX} were extrapolated. The isoinertial method produced significantly higher PPO ($p < 0.001$) and T_{MAX} ($p < 0.001$) than the isovelocity method. However, the isovelocity method produced significantly higher C_{OPT} ($p < 0.001$) and C_{MAX} ($p = 0.002$). Both sprint cycling tests showed high levels of between-session reliability (isoinertial 2.9 – 4.4%; isovelocity 2.7 – 4.0%). Functional measures of isovelocity and isoinertial sprint cycling tests were highly reliable but cannot be used interchangeably.

Key Words: Maximum power; pedalling; torque; cadence

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INTRODUCTION

Peak power output (PPO) can be defined as the highest instantaneous neuromuscular power that can be produced during a short, maximal effort (<7 s) [11,20,24], and is one of the main physiological indices that has been shown to predict sporting performance in events and tasks including sprint running [5,12,27] jumping, [10,12] rowing [15] and track sprint cycling [7]. In sprint cycling, PPO occurs at the apex of the largely parabolic power-cadence (P-C) relationship, where power is the product of the torque and cadence, which have been widely documented to have an inverse, linear torque-cadence (T-C) relationship [1,9,11,20]. Typically, PPO and the respective optimal cadence (i.e. cadence at PPO; C_{OPT}) occurs at ~50% of the extrapolated axis intercepts of maximum torque (T_{MAX}) and cadence (C_{MAX}) [6,11,17]. PPO and the underlying P-C and T-C relationships, specifically T_{MAX} , C_{MAX} and C_{OPT} , are widely used to monitor, understand/improve sprint cycling performance [7,11,18].

There are two main laboratory methods used to measure PPO and establish P-C and/or T-C relationships in sprint cycling: 1) the isoinertial method which involves participants maximally pedal against a constant load from a stationary or rolling start. The aim is to achieve the highest cadence as quickly as possible and typically involve isoinertial resistance, provided by accelerating a flywheel, sometimes with additional frictional resistance; [7,11] and 2) isovelocity method, which involves a series of maximum efforts against a range of fixed, pre-defined cadences [21,23]. Both methods have been used extensively to monitor sprint cycling performance as they are relatively easy to conduct [8,20] and have been shown to provide valid measures of PPO.

The isoinertial method with its changing cadence throughout is considered highly relevant to track sprint cycling [11,20] and can be assessed in a single effort. However familiarisation is recommended regardless of cycling experience [19,22]. In contrast the

1 isovelocity method typically involves a number of 3-4 s maximal sprints, each at a pre-defined
2 cadence [21,23]. This method involves collection of more data during a greater number of
3 efforts.

4 Previously, isovelocity and isoinertial methods had been compared, demonstrating
5 that both methods had very good levels of reliability for measuring PPO (Spearman's
6 correlation coefficient 0.97 – 0.98) [2]; and that the isovelocity method measured higher PPO
7 than the isoinertial method (combination of flywheel and frictional resistance) [2]. Previous
8 studies have made assessments of T-C and P-C relationships using different methods, which
9 have been suggested as valid measures of T-C, P-C or PPO [20]. But each of these studies
10 have only focused on one type of sprint cycling test [11,16,20,22]. Both isovelocity and
11 isoinertial methods are suggested to be valid measures of T-C and P-C relationships,
12 therefore it could be possible to use them interchangeably; however, no study has
13 systematically tried to address this idea. In addition, there have been no studies that compare
14 two different sprint cycling tests and assessing in-depth performance measures (i.e. PPO,
15 T_{MAX} , C_{MAX} and C_{OPT}) along with establishing reliability measures (i.e. coefficient of
16 variation) using the same ergometer with trained cyclists. Such information will inform
17 coaches, practitioners and clinicians to understand whether P-C and T-C relationships from
18 isoinertial and isovelocity sprint tests are repeatable and suitable for longitudinal monitoring.
19 Accordingly, the aim of this investigation was to compare the magnitude and reliability of
20 PPO, T_{MAX} , C_{MAX} and C_{OPT} measured from isovelocity and isoinertial sprint cycling methods.

21

22 **METHODOLOGY**

23 Twenty, trained male cyclists volunteered to participate (mean \pm SD age, 27 ± 5 yr;
24 stature, 183.1 ± 8.4 cm; mass, 84.1 ± 11.1 kg). All participants were engaged between 5-24 h
25 of training per week and were regularly competing in various disciplines from sprint track to

1 road endurance cycling and at a range of competitive standards according to British Cycling
2 categorisation from ‘3rd Category’ to ‘Elite Category’. With the exception of four cyclists, all
3 had track accreditation and regularly competed in a track league. All testing was done during
4 the track cycling season. Ethical approval was obtained from Northumbria University Research
5 Ethics Committee and met the ethical standards set by this journal [13]. Following a health
6 screening for possible contraindications to the protocol, participants provided written, informed
7 consent prior to the experimental procedures. Cyclists were instructed to avoid caffeine and
8 food for 3 h prior to testing and to avoid strenuous exercise in the 36 h before each session.

9 Cyclists attended the laboratory on four separate occasions, each separated by 2-7 days
10 and conducted at the same time of day (± 1 h). All laboratory sessions were identical, however
11 the first two visits were classed as familiarisation to ensure all cyclists were fully accustomed
12 with the testing procedure as has previously been suggested [22] and the last two were
13 experimental (measurement) sessions.

14 The cyclists performed efforts on a modified cycling ergometer and all completed a
15 standard 10-minute warm-up pedalling at 100–150 W and 80–90 RPM. Subsequently, they
16 performed, in a randomised crossover order, both the isovelocity sprint method and isoinertial
17 sprint method during the experimental sessions. There was at least 15 minutes of passive rest
18 between the two sprint methods in order to get full recovery before commencing the subsequent
19 test.

20 Warm-up and both sprint cycling methods were performed on the same modified SRM
21 ergometer (Schoberer Rad Messtechnik, Jülich, Germany). In brief, the SRM ergometer was
22 modified with a motor to accelerate the flywheel to the prescribed velocity of the isovelocity
23 sprints. The original cranks were replaced with 170 mm instrumented cranks to record
24 instantaneous torque, crank angle, and angular velocity (Factor Cranks, BF1 Systems, Diss,
25 UK). Crank data was wirelessly transmitted to the data logger (BF1 Systems, Diss, UK) which

1 recorded at a sampling rate of 200 Hz. Subsequently, the data was imported off-line into a PC
2 utilising Spike2 software (version 7.11, CED, Cambridge, UK) and analysed using custom
3 scripts to calculate mean torque, power and cadence per revolution. Participants wore their own
4 cycling shoes and pedals (fitted to the ergometer) and the ergometer was adjusted to the
5 participants cycling geometry. They were instructed to perform each recorded effort in the
6 saddle whilst using the 'drop' handlebars.

7 The isovelocity sprint method consisted of five maximal cycling sprints at 60, 110, 120,
8 130 and 180 RPM. The order of cadences were randomly assigned for every visit. Prior to each
9 effort, the cranks were turned on and the motor speed was brought up to match the desired
10 cadence. The participants were then instructed to pedal lightly below the prescribed cadence
11 and told to 'attack the effort as fast and as hard as possible' throughout each sprint. The
12 investigator gave a 3 s countdown and the participants performed a 4 s maximal effort at each cadence.
13 In total, each laboratory visit consisted of 2 isoinertial sprints that were separated by 8 minutes of
14 passive rest and 5 isovelocity sprint efforts with each effort separated by 3 minutes of passive rest;
15 between each test, 15 minutes of passive rest was allocated.

16 A constant isoinertial load disc (4.6 kg) and an intermediate gear ratio (front 53; rear
17 15) was used for the isoinertial sprint test. Prior to each sprint, the flywheel was brought to a
18 complete standstill and participants assumed their starting position of the cranks (typically had
19 their front leg between 45 – 90° from top dead centre [TDC]). Participants were reminded to
20 achieve the 'highest cadence possible by pedalling as hard and as fast as possible' and 'attack
21 the effort as hard and fast as possible'. Subsequently, a 5 s countdown was given to start an
22 effort. After 6 s the investigator verbally terminated the test. Participants performed two
23 isoinertial sprint tests separated by 8 min of passive rest. The sprint with the highest
24 interpolated PPO was used for analysis.

25 For the isovelocity method, the revolution with the highest average power output at
26 each pre-determined cadence was used to form the P-C and T-C relationships. For the

1 isoinertial method, the effort with the highest PPO was used for analysis, and the first five
2 revolutions from the onset of crank movement were analysed. This ensured the same number
3 of revolutions (data points) were used to form the P-C and T-C relationship with each method.
4 Individual P-C relationships were fitted with a quadratic function and the values of power and
5 cadence at the apex defined as PPO and C_{OPT} , respectively. Individual T-C relationships were
6 fitted with a linear function and extrapolated in both directions to calculate axis intercepts at
7 zero cadence (T_{MAX}) and zero torque (C_{MAX}).

8 Data are presented as mean \pm SD or mean (90% CI). When assessing the magnitude of
9 the performance measures (PPO, T_{MAX} , C_{MAX} and C_{OPT}) between sprint cycling methods, data
10 from both experimental sessions were averaged to give criterion values for each method.
11 Subsequently, a paired t-test was used to assess whether any difference between measures
12 between the respective methodologies (i.e. isovelocity vs isoinertial for PPO, T_{MAX} , C_{MAX} and
13 C_{OPT}) were significant. A Pearson's product-moment correlation analysis was carried out to
14 report the strength of the relationships. To interpret the magnitude of the relationship (r)
15 between both sprint cycling method measures, the following scale was used: <0.1 , trivial; 0.1 –
16 0.29 , small; 0.3 – 0.49 , moderate; 0.5 – 0.69 , large; 0.7 – 0.89 , very large; and 0.9 – 1.0 , almost
17 perfect. [14]

18 All the performance measures of the two sprint cycling methodologies had their
19 between-session reliability assessed by: 1) using a paired t-test to establish whether any
20 between-session differences were significant; 2) Coefficient of variation (CV%) (which was
21 calculated by $SD/mean$); 3) A paired t-test was used to assess any significant differences
22 between CV% of respective measures for both tests; 4) Intraclass correlation coefficient (ICC).
23 Previously, a CV of $\leq 5.0\%$ was considered as good between-session reliability for
24 performance tests [4] and significance was set at $P < 0.05$.

25

1 RESULTS

2 The two methods produced significant differences in the P-C and T-C relationships, as
3 indicated by all four metrics of these relationships (Figure 1 and Table 1). PPO was higher (45
4 W, 3.8%) with the isoinertial method than the isovelocity method (1242 ± 196 W vs. $1197 \pm$
5 203 W; $P < 0.001$). The isovelocity method produced higher C_{OPT} (124 ± 11 RPM vs. 117 ± 11
6 RPM; $P < 0.001$) and C_{MAX} (248 ± 22 RPM vs. 236 ± 19 RPM; $P = 0.002$), however a lower
7 T_{MAX} (173 ± 26 N.m. vs. 198 ± 34 N.m; $P < 0.001$). Despite these differences in the outcome
8 measures from the two methods, near perfect (PPO $r = 0.97$; T_{MAX} $r = 0.94$) or very large
9 relationships (C_{OPT} $r = 0.85$; C_{MAX} $r = 0.74$) were seen between the two methods (Figure 2 and
10 Table 1).

11 All measures for the two sprint cycling methods were consistent and similar (i.e.
12 unchanged) between the first and second experimental sessions (Table 2). All measures for
13 both tests were categorised as having good levels of between-session reliability (i.e. $CV \leq$
14 5.0%), however there were no differences in reliability ($CV\%$) between the two methods and
15 ICC was measured at or above 0.75 for all measures of both methods which is detailed in Table
16 2.

17

18 DISCUSSION

19 Both the P-C and T-C relationships measures were different between the two methods
20 of assessing sprint cycling performance and thus these methods cannot be used
21 interchangeably. The isoinertial method produced more vertically orientated T-C relationship
22 with a higher T_{MAX} and lower C_{MAX} , and consequently a P-C relationship further to the left,
23 that had a lower C_{OPT} and also a higher PPO in comparison to the isovelocity method.
24 Nonetheless, there were very large to near perfect relationships between the measurements
25 taken during both methods ($r = 0.75 - 0.97$). The data in this study also showed high levels of

1 between-session reliability (i.e. $CV \leq 5.0\%$ and $ICC \geq 0.75$) when measuring PPO, C_{OPT} , T_{MAX}
2 and C_{MAX} with both methods.

3 The isoinertial method showed significantly higher PPO (~45W). In addition, the
4 isoinertial method showed higher T_{MAX} and lower C_{MAX} in comparison to the isovelocity
5 method. The C_{OPT} was also achieved at different cadences depending on the method, being
6 higher for isovelocity than isoinertial (124 vs 117 RPM), although C_{OPT} with both methods was
7 in the range of previously reported values (between 110 - 130 RPM [3]). The observation that
8 every measure (i.e. PPO, T_{MAX} , C_{OPT} and C_{MAX}) was different between the methods of
9 assessing sprint cycling, strongly suggests that both methods cannot be used interchangeably
10 to ascertain changes in the P-C and T-C relationship.

11 Our finding of higher PPO and T_{MAX} using the isoinertial method and higher C_{MAX} and
12 C_{OPT} with the isovelocity method was largely in contrast to a previous study that reported PPO
13 and C_{OPT} to be higher with the isoinertial method and no differences in T_{MAX} and C_{MAX} [2].
14 The major differences between the experiments were two-fold. Firstly, acceleration method
15 (i.e. flywheel plus friction) was used instead of isoinertial sprint test. Secondly, the participants
16 had no previous experience of cycling. Therefore, the discrepancy between this study and that
17 of Baron and colleagues may be linked to one or both of those factors. [2]

18 The lower isoinertial C_{OPT} and C_{MAX} may potentially be attributed to potential fatigue
19 throughout the isoinertial effort. It has been suggested that fatigue in maximal cycling is
20 revolution dependent, rather than time dependent, and power output can reduce at a rate of
21 0.5% per revolution [26]. The P-C relationship of the isoinertial method was established in 5
22 revolutions, hence the power output could be reduced by 2.0 -2.5% by the fifth revolution. In
23 comparison, the addition of the motor during isovelocity assessment allowed participants to
24 pedal with no resistance until they had achieved the pre-required cadence, meaning that the
25 isovelocity efforts are relatively fatigue-free due to minimal effort involved in accelerating to

1 the required cadence and analysis of the single highest revolution at each velocity/sprint.
2 Collectively, this could contribute to the higher isovelocity C_{OPT} and C_{MAX} compared to the
3 isoinertial method, and thereby provide a better indication of the actual C_{OPT} and C_{MAX} .
4 Additionally, the methodology of calculating power output can be attributed to the difference
5 in P-C and T-C relationships between PPO methods. Torque and cadence in cycling is
6 calculated by multiplying mean torque and cadence per revolution [20]. Isoinertial cycling,
7 unlike isovelocity cycling is not performed under fixed cadences and the change in
8 cadence/acceleration of the flywheel throughout the effort is neither constant, nor linear.
9 Therefore, cadence when measured by averaging over a revolution reads higher in an isoinertial
10 effort compared to isovelocity efforts and we suggest over-estimates the actual physiological
11 PPO, but underestimates C_{MAX} and therefore, C_{OPT} . IsovLOCITY cycling minimises the effect of
12 potential fatigue and eradicates variable changes in cadence. If these explanations are correct, it
13 suggests that isovelocity cycling is more suited to establish a fatigue-free physiological measure of the
14 P-C and T-C relationships in sprint cycling whilst the acceleration of the isoinertial cycling arguably
15 provides be a more ecological method.

16 Between-session reliability of the measures from both sprint cycling methods were
17 classed as good ($\leq 5.0\%$) and there were no differences in CV between the two methods. These
18 levels of good reliability are consistent with other studies where they have had a similar number
19 of familiarisation sessions when assessing PPO using similar sprint cycling methods [2,20,22].
20 Previous studies that have reported reliability have mainly focused on reporting PPO [19,20,22]
21 and in one case, C_{OPT} [19]. None have specifically focused on the reliability of T_{MAX} and C_{MAX} .
22 Martin and colleagues suggested that irrespective of experience in cycling, familiarisation to
23 the task is recommended to produce reliable PPO [19]. Yet, they also suggested that
24 irrespective of their cycling experience, no significant differences were measured in C_{OPT}
25 between sessions or efforts. Due to the good reliability found for both methods of assessing

1 sprint cycling in the current study, either method could be effective for monitoring cycling
2 performance (PPO) and the underlying P-C and T-C relationships (T_{MAX} , C_{MAX} and C_{OPT}).

3 The isoinertial load of the flywheel (4.6 kg) and gear ratio (3.5:1) used in this
4 experiment were somewhat lower than those that have previously been used (up to 8.4 kg and
5 7.4:1) [11,25] making the inertial load of the isoinertial method considerably lower than
6 previous experiments. Based on our pilot work the flywheel load and gear ratio used in this
7 experiment were selected to produce a similar number of full revolutions (i.e. 5) during the
8 isoinertial sprints to those prescribed for the isovelocity sprints.

9

10 **CONCLUSION**

11 Both isoinertial and isovelocity sprint cycling tests present good reliability when measuring
12 PPO, P-C and T-C relationships. However, when monitoring and comparing any measure, they
13 should not be used interchangeably.

14

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Table 1: Magnitude of isovelocity and isoinertial sprint cycling methods. Measurements that are presented are: peak power output (PPO), optimal cadence (C_{OPT}), maximal torque (T_{MAX}) and maximal cadence (C_{MAX}). Overall mean difference (Diff.); Pearson correlation coefficient (r) and respective r rating; * denotes significant difference to other respective sprint cycling method.

	Isovelocity	Isoinertial	P-Value	Diff.	r	r Rating
PPO (W)	$1197 \pm 203^*$	$1242 \pm 196^*$	<0.001	45	0.97	Almost perfect
C_{OPT} (RPM)	$124 \pm 11^*$	$117 \pm 11^*$	<0.001	7	0.85	Very Large
T_{MAX} (N.m)	$177 \pm 28^*$	$198 \pm 34^*$	<0.001	25	0.94	Almost Perfect
C_{MAX} (RPM)	$248 \pm 19^*$	$236 \pm 26^*$	0.002	12	0.75	Very Large

1 Table 2: Between session reliability from isoinertial and isovelocity sprint tests. Experimental lab visit 1 (Exp 1) and lab visit 2 (Exp 2) (n = 20)
 2 of isoinertial and isovelocity peak power output (PPO), maximal torque (T_{MAX}), maximal cadence (C_{MAX}), optimal cadence (C_{OPT}); P-value
 3 which evaluates whether there are any significant differences between Exp 1 and Exp 2 with respective measures; Coefficient of variation (CV);
 4 P-value of CV that assesses any significant difference between the CV of a measure between respective methods; intraclass correlation (ICC).

5
6

		Exp 1	Exp 2	Between Session P=	Between Session CV, %	Between Methods CV% P=	Between Session ICC (90% CI)
PPO (W)							
	Isoinertial	1237 ± 86	1248 ± 86	0.442	2.9	0.601	0.98 (0.96 - 0.99)
	Isovelocity	1203 ± 87	1192 ± 98	0.466	2.7		0.96 (0.92 - 0.98)
C_{OPT} (RPM)							
	Isoinertial	117 ± 9	116 ± 9	0.358	3.5	0.283	0.80 (0.61 - 0.90)
	Isovelocity	125 ± 10	123 ± 9	0.157	2.7		0.73 (0.50 - 0.87)
T_{MAX} (N.m)							
	Isoinertial	197 ± 33	198 ± 34	0.764	4.4	0.499	0.87 (0.73 - 0.94)
	Isovelocity	178 ± 31	177 ± 28	0.604	3.6		0.94 (0.87 - 0.97)
C_{MAX} (RPM)							
	Isoinertial	238 ± 22	235 ± 19	0.381	3.1	0.377	0.83 (0.66 - 0.92)
	Isovelocity	253 ± 24	252 ± 27	0.782	4.0		0.83 (0.67 - 0.92)

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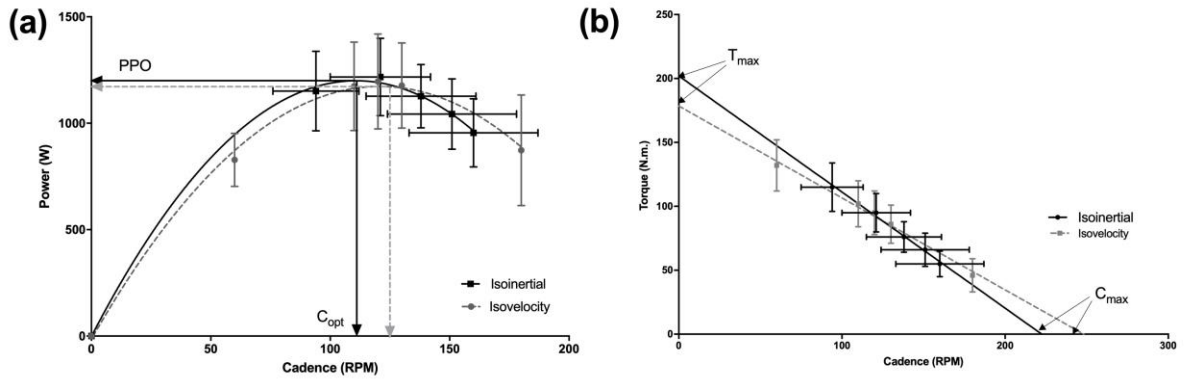


Figure 1: (a) Power-cadence relationship of both isoinertial and isovelocity sprint cycling methods. The apex of the parabolic relationship represents peak power output (PPO) and cadence at PPO represents optimal cadence (C_{OPT}); (b) Torque-cadence relationship of isoinertial and isovelocity sprint cycling tests. The linear relationships have been extrapolated to the axis intercepts in order to calculate maximal torque (T_{MAX}) and cadence (C_{MAX}). Data are presented as mean \pm SD (n=20).

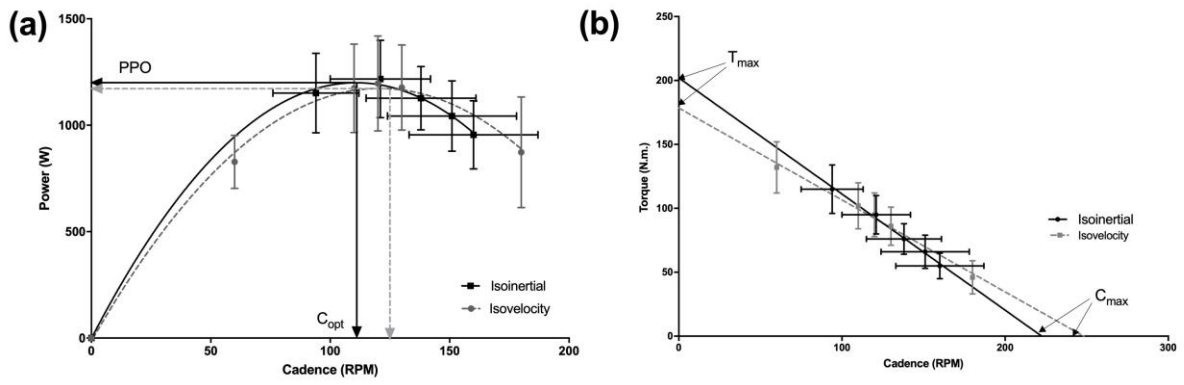


Figure 2: Relationships of (a) Peak Power Output (PPO); (b) Maximal Torque (T_{MAX}); (c) Maximal cadence (C_{MAX}); (d) Optimal cadence (C_{OPT}) from isoinertial and isovelocity sprint cycling tests ($n = 20$)

