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REPRODUCIBILITY OF PEAK POWER OUTPUT DURING A 10-S CYCLING MAXIMAL EFFORT USING DIFFERENT SAMPLING RATES

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RUNNING HEAD:
Assessment of reliability in peak output derived from 10-s cycling sprint

ABSTRACT:

The study was aimed to investigate the reproducibility of performance parameters obtained from 10-s sprints against different braking forces in young adult athletes. The sample (n=48) included male athletes aged 18.9-29.9 years (175.5±6.9 cm, 76.2±10.1 kg). The 10-s maximal exercise was performed in a cycle-ergometer against a random braking force (4% to 11% of body mass). Intra-individual variation was examined from repeated tests within one week. Descriptive statistics were computed and differences between sessions tested using paired-*t* test. The coefficient of correlation between repeated measures, technical error of measurement (TEM), coefficient of variation and ICC were calculated. Agreement between trials was examined using the Bland-Altman procedure. Mean values of peak power were relatively stable when obtained from sampling rates of 50 Hz and ranged between 1068 watt and 1082 watt ($t_{(47)}$=1.149, p=0.256, ES-r=0.165) or while corresponding to the best second from the 10-s row data ($t_{(47)}$=0.742, p=0.462, ES-r=0.107). Correlations between repeated measures were high (+0.907, 95%CI: +0.839 to +0.947) and TEM about 59.3 watt (%CV=5.52%; ICC=0.951, 95%CI: 0.912 to 0.972). The present study suggests that reproducibility of peak power in male adult athletes tended to be acceptable.

KEY WORDS:
Anaerobic power
technical error of measurement
reliability
intra-class correlation
Bland-Altman plot
short-term maximal intensity effort
cycle-ergometer

INTRODUCTION

Maximal mechanical power generated by skeletal muscle is usually estimated with popularized vertical jump (31) that has the dimension of work not power. Although, several formulae have been proposed to add velocity to the body mass and vertical height components (15), the validity is questionable (2). Height jump is a function of the product of force and time, not the product of force and velocity. A 30-s friction-braked cycle ergometer protocol (Wingate test, WAnT) was introduced in 1971 (8) and is probably the most used cycle ergometer protocol. It involves pedalling for 30 seconds against a constant braking force. The original research using the WAnT (8) adopted the same braking force for all participants (adolescents aged 12-17 years), but the subsequent versions of the test have related the braking force to body mass (3). Standardized braking force of 0.74 $N.kg^{-1}$ is commonly used in children and adolescents (1, 14).

Power output is conventionally calculated from the formula that considers the product of angular velocity of the flywheel (in $rad.s^{-1}$) and the resistive torque in N.m (given by the product of the braking force and the radius of the flywheel). This method does not take into account amount of work to overcome the inertia of the flywheel and the internal resistance and results obtained from different ergometers should be interpreted with caution. Apart of this, maximal power or peak power (PP) corresponds to optimal values of force (F_{opt}) and velocity (V_{opt}) and the relationship largely depends on the types of muscle fibers (7, 27). The force-velocity test (FVT) overcomes the methodological constraints experienced by the WAnT regarding braking force related to body mass. It assumes a quasi-linear relation between braking force and angular velocity, and a parabolic function between braking force and power that is evident between 50 and 150 $rev.min^{-1}$ (33, 34).

Peak power outputs in WAnT and FVT is generally obtained over 1-s to 5-s epochs. With the relative ease and popularity of computer driven data collection systems, estimates of peak power over several time periods (1-, 3- or 5-seconds) are possible and facilitate comparisons among data following different procedures. In the initial description of the test (3), peak power output corresponded to the highest 5-s mean power. Few authors still adopt the 5-s interval to obtain peak power (6). The influence of age, sex, body size, skinfold thickness, thigh volume and isokinetic strength on peak power, for example, was estimated from the WAnT using a measure of peak power output over 1-s (9). At present, pedaling rate can be measured at a high sampling frequency, while peak power can be measured more accurately over shorter intervals. More recently, accurate assessments of power during a WAnT was examined using a sampling frequency of 50 Hz (16). Peak output appeared dependent on sampling rate (0.5 or 1 s) and it was suggested that a better to measure velocity would be the average of a revolution rather than the average over a given time interval (11).

This study investigates the reproducibility of performance parameters on a 10-s maximal sprint against different braking forces in male adult athletes. It also considers the reproducibility of peak power provided by the cycle ergometer at a precision of 50 Hz and the score sampled at 1 Hz from the 10-s interval, and the reproducibility of time at maximal power and at maximal velocity.

MATERIALS AND METHODS

Peak output was measured on a 10-s cycle-ergometer sprint in male athletes aged 18.9-29.0 years. The athletes were participants in several sports (judo, soccer, badminton, volleyball, track and field, swimming, aquatic polo, tennis, surf and karate). Forty-eight repeated assessments were made within a period of one week. Participation was voluntary and informed consent was obtained in compliance with the *Declaration of Helsinki* (17).

Participants were instructed not to eat for at least 3-h and not to drink coffee or beverages containing caffeine for at least 8-h before each testing session. No participant was suffering from musculoskeletal injury of the lower extremity at the time of testing or injury in the preceding 6 months that limited activity for more than 48 hours. Anthropometry was done by a single experienced observer according to standardized procedures (20). Stature was measured with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Body mass was measured with a portable balance (Seca model 770, Hanover, MD, USA) to the nearest 0.1 kg. Intra-observer technical errors of measurement were 0.5 cm for stature, 0.8 kg for body mass. These errors were within the range reported for in variety of studies (23).

After measurement of stature and body mass, all participants completed a standardized warm-up of 4-min pedaling with minimal resistance (basket supported) at 60 rev min^{-1}

interspersed with three “all-out” sprints of 2-s to 3-s followed by static stretches of the quadriceps and hamstring muscles. A Monark 894 Peak Bike (Monark AB, Varberg, Sweden) with the capacity for a sampling frequency of 50 Hz was used; the data were transferred directly to a computer. Subsequent analyses were performed with ATS software recommended for the ergometer by the manufacturer. Calibration was also done before each test session according to recommendations of the manufacturer.

The experimental protocol test involved a maximal exercise bout against randomly selected braking forces (range 4%-11% of body mass). The test began with a rolling start (weight basket supported pedaling at 60 rev.min^{-1}); on the command “ready, go!”, the subject began maximal effort pedaling with the braking force simultaneously applied. Strong verbal encouragement was given throughout the exercise bout. Two peak power outputs were considered for subsequent analyses: PP-1Hz corresponded to the best score with data sampled at 1 HZ, and PP-50Hz obtained using a sampling rate of 50 Hz. The highest sampling rate permitted the collection of time at maximal power and time at maximal velocity.

Descriptive statistics for age, stature, body mass and replicate sprint measurements were computed for the total sample. Means and standard deviations of PP-1Hz, PP-50Hz, time ad peak power and time at maximal velocity were calculated for each time moment. Differences between the replicate tests were evaluated with paired-*t* test analysis. Effect size was estimated using the square root of the ratio of the *t*-value squared and the sum of the *t*-value squared and degrees of freedom (28). Coefficients of correlation between repeated measures, technical errors of measurement, coefficients of variation (TEM divided by the mean of two trials) and ICC were calculated. Levels of agreement between trials were also examined using the Bland-Altman procedure (5). Pearson correlations between the means and differences of two trials for peak power output (PP-1Hz, PP-50Hz) and stature and body mass were also calculated. Coefficients were interpreted as recommended (18): trivial ($r < 0.1$), small ($0.1 < r < 0.3$) moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$) and nearly perfect ($r > 0.9$) and perfect ($r = 1$). Statistical significance was set at $p<0.05$ and all analyses were performed using the Statistical Package for the Social Sciences version 17.0 (SPSS, Chicago, IL).

RESULTS

Descriptive statistics for chronological age, anthropometry, braking force and peak power outputs are given in Table 1. Mean values for the two measures of peak power (PP-1Hz, PP-50Hz) slightly decreased from the initial to the second sessions: 14 and 10 watt respectively for PP-1Hz and PP-50Hz. However, as shown in Table 2, the mean differences between sessions 1 and 2 were not significant.

[Table 1 about here]

[Table 2 about here]

Bivariate correlations between repeated measures of peak power output were high and significant: PP-1Hz (+0.893) and PP-50Hz (+0.907). Technical errors of measurement (TEM) are summarized in Table 3 for PP-50Hz (CV=5.52%) and for PP-1Hz (CV=6.10%). Estimated coefficients of reliability (25) were 0.905 for PP50Hz and 0.891 for PP-1Hz. Corresponding ICC were 0.951 for PP-50Hz and 0.941 for PP-1Hz.

[Table 3 about here]

Correlations of peak power and body size are summarized in Table 4. The two peak power measures were moderately correlated with stature, but poorly correlated with body mass. The differences between repeated measures of peak power were poorly correlated with body size given by stature and body mass. The Bland-Altman plots (Figures 1 and 2) suggested that the magnitude of the differences between repeated assessments were within the range of normal variation for the sample.

[Table 4 about here]

[Figure 1 about here]

[Figure 2 about here]

DISCUSSION

Peak power outputs did not significantly differ between repeated trials (Table 2). The results contrast those from a study of repeated assessment of peak cycling power in physical education students of both sexes under four applied braking forces, 2.5%, 5.0%, 7.5% and

10.0% of body mass (10). In the French study, performances improved substantially between sessions from 1025±219 watt to 1069±243 watt. The study, however, did not include a habituation session prior to the protocol, which leaded the authors to recommend inclusion of a previous session for habituation.

Few studies have examined intensity-associated variation in the reliability of peak power output generated in a single "all-out" 10-s episode. The studies have examined estimated optimal peak power derived from the parabolic relationship between breaking force and peak power. A quasi-linear relation between braking force and angular velocity, and a parabolic function between braking force and power were noted between 50 and 150 rev.min^{-1} (33, 34). The results implied a need to evaluate the assumption of the FVT above these limits. It was suggested that at peak velocity (usually ≥ 200 rpm) of an all-out test against the inertia of the flywheel, peak torque would occur at pedal angles between 140 and 150 degrees, i.e., before the end of the downward pedal motion. This is substantially different from peak torque during a single revolution observed around 90 degrees when pedal rate is low to medium (26). Of potential relevance, it has been suggested that most of the power in the downstroke during maximal sprint cycling is produced at the hip and not at the knee as in submaximal cycling (13, 24).

The FVT protocol assumes a quasi-linear relation between braking force and angular velocity, and a parabolic function between braking force and power that is evident between 50 and 150 rev.min^{-1} (33, 34). The protocol is increasingly used (4, 12, 19, 32) and provides a promising model for research. However, reports on its reliability are still limited. The number of sprints, rest interval between episodes, randomization of braking forces, standardization of the warm-up protocol and sport background of participants are potential sources of variation that need consideration. The current study examined the observed peak obtained in a single 10-s "all-out" episode against braking forces randomly selected between 4.1% and 11.4% of body mass (Table 1). The breaking force for each athlete was exactly the same in the two sessions, but was not constant among subjects. In a related study using "all-out" sprints against four braking forces until maximal speed (10). Available technology permits that a particular assessment is immediately stopped after the detection of a decline for three consecutive revolutions (29) to reduce fatigue by subtracting each sprint by about 2-5 seconds, which corresponded to a total of 8-20 seconds in the sum of four "all-out" episodes.

The expression of peak output is quite variable in the literature, which makes it difficult to compare studies. Peak power output is expressed for a large range of sampling rates (0.2 Hz to 50 Hz) and also as a mean value over 1-s, 3-s or 5-s periods which result in smoothed curves (30). Among 26 physically active non-athlete young males, for example, peak power was substantially attenuated when sampling rates were 0.2 Hz compared to high sampling rates (>5 Hz). Time to attain peak power output was markedly delayed, 54%, from >5Hz to low sampling rates of 0.2 Hz. According to the sampling theorem, if H is the highest frequency of any continuous function, then the sampling rate must be at least twice H to allow for perfect signal reconstruction and to avoid distortion known as aliasing (21, 22). Mean peak pedaling rate in the present study was 142±17 rotations.min^{-1} (range: 110-188 rotations.min^{-1}) assuming a sampling rate of 2.5-3.0 Hz. This corresponds to a recommendation for a sampling rate at least 5.0-6.0 Hz.

In the present study, scores obtained at 50 HZ did not substantially differ from scores sampled at 1 second (PP-1Hz) over a period of 10-s (17 watt in time moment 1, 13 watt in time-moment 2). The differences were similar to the mean differences between time moments (14 watt for PP-50HZ, 10 watt for PP-1Hz). The mean difference between sessions was 44 watt in the study of physical education students (10). Note, however, this study used a calibrated friction-braked ergometer (Ergomeca, Sorem, Toulon, France) without information on sampling frequency.

In summary, the reproducibility of peak power in adult male athletes in several sports is acceptable when derived from an ergometer that provides sampling rates of 50 Hz. Differences between repeated sessions (error) were not significantly correlated with body size or braking force expressed as a percentage of body mass. This is highly relevant since error associated with braking force (Fb) would affect the parabolic relationship between Fb and peak power output. Moreover, technical errors of measurement, coefficients of reliability and Bland-Altman 95 % limits of agreement indicated that force-velocity measures were reasonably reliable in trained adults. Standardization of test procedures, including an appropriate session of habituation are recommended, specially among untrained participants, and results from studies that adopted distinct sampling rates should be interpreted with care. it is believed that the potential impact in peak power output due to the precision of the sampling rate may be more apparent in protocols adopting 0.2 Hz (power output sampled over a 5-s period).

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Table 1. Descriptive statistics (n=48).

Variables	Range		Mean		Standard deviation
	Minimum	Maximum	Value	(95% CI of mean)	
Chronological age, yrs	18.9	29.9	21.6	(20.7 to 23.0)	3.1
Stature, cm	161.5	188.3	177.5	(175.5 to 179.5)	6.9
Body mass, kg	52.3	93.7	76.2	(73.3 to 79.2)	10.1
Braking force, kg	3.6	9.2	6.5	(6.1 to 6.9)	1.4
Braking force/Body mass, %	4.1	11.4	8.5	(8.1 to 9.0)	1.5
Time moment 1					
Peak power (PP-50Hz), watt	566	1406	1082	(1024 to 1139)	198
Time at peak power (50 Hz), ms	1.15	5.34	2.41	(2.09 to 2.72)	1.10
Time at maximal angular velocity (50 Hz), ms	3.24	8.22	5.02	(4.70 to 5.34)	1.11
Peak power (PP-1Hz), watt	560	1592	1065	(1006 to 1124)	204
Time moment 2					
Peak power (PP-50Hz), watt	513	1389	1068	(1013 to 1122)	188
Time at peak power (50 Hz), ms	1.03	4.72	2.36	(2.10 to 2.62)	0.91
Time at maximal angular velocity (50 Hz), ms	3.20	8.21	4.98	(4.71 to 5.25)	0.92
Peak power (PP-1Hz), watt	507	1363	1055	(1001 to 1110)	187

Table 2. Mean and standard deviation at each test session, mean difference between tests and respective 95% confidence intervals, and results of paired t-tests (n=48).

	Time moment 1		Time moment 2		Mean		t	df	p	ES
	Mean	SD	Mean	SD	difference	(95% CI)				
Peak power (PP-50Hz), watt	1082	198	1068	188	13.9	(-10.4 to +38.1)	1.149	47	0.256	0.144
Time at peak power (50 Hz), ms	2.41	1.10	2.36	0.91	0.05	(-0.19 to +0.29)	0.396	47	0.694	0.058
Time at maximal angular velocity (50 Hz), ms	5.02	1.11	4.98	0.92	0.04	(-0.21 to +0.30)	0.322	47	0.749	0.047
Peak power (PP-1Hz), watt	1065	204	1055	187	9.9	(-16.9 to +36.6)	0.742	47	0.462	0.108

95%CI (95% confidence interval); df (degree of freedom)

Table 3. Correlations between sessions, technical errors of measurement (TEM), coefficients of reliability and variation, and intraclass correlation coefficients (ICC) and respective 95% CI (n=48).

	Coefficient of correlation			TEM	Coefficient of reliability (R)	Coefficient of variation (CV)	ICC	
	r	(95% CI)	p				value	(95% CI)
Peak power (PP-50Hz)	0.907	(0.839 to 0.947)	<0.001	59.3	0.905	5.52%	0.951	(0.912 to 0.972)
Peak power (PP-1Hz)	0.893	(0.816 to 0.939)	<0.001	64.7	0.891	6.10%	0.942	(0.896 to 0.967)

95%CI (95% confidence interval)

Table 4. Correlations between the means of two trials and the differences between repeated measurements of peak power obtained from sampling rates of 50 Hz (Y) and 1 Hz (Y') with body size and with braking force expressed as a percentage of body mass (n=48).

(X_i: variables)	Y: Peak power (PP-50Hz)				Y': Peak power (PP-1Hz)			
	Y_1: Mean two trials		Y_2: Difference between trials		Y'_1: Mean two trials		Y'_2: Difference between trials	
	$r_{(x,y)}$	(95% CI)	r	(95% CI)	$r_{(x,y')}$	(95%CI)	r	(95% CI)
Stature	+0.584	(+0.350 to +0.745)	-0.172	(-0.435 to +0.118)	+0.596	(+0.375 to +0.753)	-0.232	(-0.484 to +0.056)
Body mass (BM)	+0.213	(-0.076 to +0.469)	-0.172	(-0.435 to +0.118)	+0.219	(-0.069 to +0.474)	-0.238	(-0.489 to +0.049)
Braking force (%BM)	+0.978	(+0.961 to +0.988)	-0.122	(-0.393 to +0.168)	+0.975	(+0.956 to +0.986)	-0.151	(-0.417 to +0.139)

95%CI (95% confidence interval)

FIGURE LEGENDS:

Figure 1. Bland-Altman plot for peak power obtained using a sampling rate of 50 Hz (n=48). Y axis is the difference in peak power between trials and the X axis is the mean of peak powers of the two trials. Mean and standard deviation of bias, lower (LLA) and upper (ULA) limits of agreement, coefficient of correlation between axes and respective 95% confidence intervals are also presented.

Figure 2. Bland-Altman plot for peak power obtained using a sampling rate of 1 Hz (n=48). Y axis is the difference in peak power between trials and the X axis is the mean of peak powers of the two trials. Mean and standard deviation of bias, lower (LLA) and upper (ULA) limits of agreement, coefficient of correlation between axes and respective 95% confidence intervals are also presented.