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A Comparison of Anaerobic Power Tests using Cycle Ergometry and Non-motorized Treadmill Ergometry at Optimized Loads

CHERILYN N. McLESTER‡1, RASMUS ROOKS†1, JOHN R. McLESTER‡1, EMILY BECHKE†2, CASSIE WILLIAMSON‡3, and BRIAN M. KLISZCZEWICZ‡1

1Department of Exercise Science and Sport Management, Kennesaw State University, Kennesaw, GA, USA; 2Department of Kinesiology, University of North Carolina-Greensboro, Greensboro, NC, USA; 3Department of Kinesiology, Berry College, Mount Berry, GA, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 16(4): 1293-1305, 2023. The purpose of this study was to compare performance markers derived from a 30-second maximal bout on a cycle ergometer (CE) and non-motorized treadmill (NMT) under optimized loads. Recreationally active participants (n = 40) volunteered for the study. Force-velocity tests on the CE and NMT were used to determine optimal resistance for peak power (PP) production. The remaining visits were randomized and counterbalanced, with a single 30-second maximal test on CE or NMT to assess PP, mean power (MP), fatigue index (FI), over the course of the 30-second test, and maximum heart rate (HR_{max}) and blood lactate (BLa^-) taken 1-minute post. Results were that PP and MP were higher ($P<0.05$) on CE compared to NMT for both sexes. FI did not differ among males ($P=0.201$) whereas females showed higher FI ($P=0.002$) on the CE. HR_{max} and BLa^- were higher ($P<0.05$) after NMT for both sexes. There was no difference for optimal braking force on NMT between males (16.65±4.49%BW) and females (14.30±3.10%BW) ($P=0.061$). CE optimal torque factor was higher for males (0.78±0.16 Nm/kg) compared to females (0.62±0.14 Nm/kg) ($P=0.001$). Overall, CE produced higher power output using optimized loads in recreationally active males and females, while NMT test resulted in a higher HR_{max} and BLa^- concentration. These tests for anaerobic power, when performed with optimized loads, produced different results for several variables, therefore these modalities should not be considered interchangeable. Practitioners should consider which modality best mimics the activities of the person being tested when selecting a protocol.

KEY WORDS: Wingate, fatigue index, peak power, mean power, perceived exertion

INTRODUCTION

The Wingate anaerobic test (WAnT) performed on a cycle ergometer (CE) is one of, if not the most commonly used laboratory test for anaerobic power since its inception in the 1970's (2,8). The 30-second test was originally developed to assess the maximal amount of ATP produced anaerobically, i.e., anaerobic capacity (5), however, longer protocols (> 2-min), such as the maximal accumulated oxygen deficit test, have been proven more suitable for this measure, as it has become evident that 30-seconds is not enough time to completely exhaust the anaerobic system (20,22). Regardless, the WAnT protocol remains appropriate for assessing anaerobic power, yielding indices such as peak power (PP), mean power (MP), and fatigue index (FI). These variables are used to evaluate the effectiveness of training programs and dietary supplements, in addition to testing athletes and analyzing their responses to maximal exercise (2,5). The WAnT continues to be a widely used test for anaerobic power in a laboratory setting in part due to its reliability and ease of administration (4,30).

Despite its popularity, the CE WAnT has drawn criticism due to limited validity and carryover to sprint-run based sports. Legaz-Arrese et al. assessed the validity of the WAnT in world-class athletes competing in distances ranging from 100m to a marathon (16) and found that PP and MP decreased for those with longer competition distances (e.g. 5K, 10K, etc.), but PP and MP failed to differentiate between 100m and 400m runners as well as 800m and 3000m runners despite the clear differences in metabolic systems being used. The recent development of specialized sprint treadmills that allow self-propelled sprinting with the measurement of kinetic and kinematic variables presents the potential for more sport-specific testing protocols (26). The presence of sprint treadmills in the research community has led to comparisons with CE WAnT protocols in order to determine modality specific differences among anaerobic power testing (8,31). Current literature demonstrates mixed results, as Falk et al. reported treadmill sprinting to produce higher power outputs when compared to cycling, while Chia and Lim reported CE to produce higher PP but not MP (3,7). Further, Zemkova and Hamar reported no statistical difference in PP or MP between the two modalities when using an isokinetic CE and sprint-treadmill (31). It is difficult to draw conclusions between these studies due to the heterogeneity in methods and protocols such as equipment, load standardization, duration of tests, as well as differences in data sampling and analysis. In order to compare the two testing modalities using the same sample of participants, the load should be individually optimized across both devices, the same test duration should be used, and starting position should be consistent. Therefore, the purpose of this study was to investigate anaerobic performance differences between a 30-second WAnT with a CE and a comparable test on a non-motorized treadmill (NMT) under optimized loads and standardized testing conditions in males and females.

METHODS

This study was approved by the university's institutional review board prior to data collection. Thorough explanation about the risks and benefits associated with the protocol was provided and written informed consent was obtained prior to data collection. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (24). Participants reported to the university's Exercise Physiology Laboratory on three occasions separated by at least 48-hours between each visit, but not exceeding 14 days total for all visits. Participants were asked to schedule their lab visits at the same time of day. The first visit (V1) consisted of the collection of descriptive data and equipment familiarization through multiple-trial force-velocity tests on the CE and NMT; this also served to determine each individual's optimal resistance setting for PP production. Demographic information was collected via a questionnaire. Height (cm) and body mass (kg) were recorded with a digital physician's scale (Tanita WB-3000, Tanita Corporation, Arlington Heights, IL, USA). Body composition was assessed with a dual-energy x-ray absorptiometry (DXA) scan (iDXA, General Electric, Madison, WI, USA). The second (V2) and third (V3) trials were performed in a randomized counterbalanced fashion, where either the CE or NMT were used.

Participants

A power analysis conducted with G*Power 3.1 (Heinrich Heine Universitat Dusseldorf) determined 32 participants were needed for this study for a power of 0.95, with an effect size of 0.6 and an $\alpha = 0.05$. A total of forty (20 male and 20 female) recreationally active participants volunteered for the study with a mean age of 24.0 ± 3.3 yrs, height 169.6 ± 7.8 cm, body mass 72.2 ± 12.6 kg, body fat % 22.4 ± 8.4, aerobic training days per week of 3.1 ± 1.6, and strength training days per week of 3.5 ± 1.8. All participants were healthy and free of any cardiovascular, pulmonary, or metabolic disease and did not have any musculoskeletal disorders or limitations as determined by a health history questionnaire. Prior to each visit participants were instructed to refrain from exercise and alcohol consumption for 24-hours, caffeine for 12-hours, and food for 4-hours, with no restrictions on water consumption.

Protocol

Dual-Energy X-Ray Absorptiometry: The DXA machine (GE Lunar Prodigy, Software version 14.10.022; GE Lunar Corporation, Madison, WI, USA) was calibrated each day before use according to manufacturer's instructions using a standard calibration block. Before positioning on the scanning bed, subjects removed shoes and anything metal (e.g., jewelry). During DXA scans, subjects laid supine and motionless with the arms by the side. When subjects were in proper position, a certified technician began the scan, which lasted approximately 6–10 minutes.

Cycle Ergometer: The CE used in this study was the electromagnetically-braked Lode Excalibur Sport (Lode B.V., Groningen, The Netherlands) with software package LEM 9.4.4.0 (Lode B.V., Gorningen, The Netherlands). Saddle, handlebar height, and forward placement of each individual were established during visit 1 and repeated for the CE bout in either V1 or V2. Sampling frequency for the cycle ergometer was set at a default of 5 Hz. Power was calculated from pedal torque and rotational speed during a revolution and averaged for a mean value. All maximal performance variables have been shown to have strong between trial reliability for the Lode Excalibur Sports (6).

Non-Motorized Treadmill: The NMT has previously been shown to be a reliable tool for measuring sprint performance (10). The NMT used in this study was the Woodway Force 3.0 (Woodway USA, Waukesha, WI, USA). Detailed information on this treadmill has previously been summarized by Sweeney et al. (27). The NMT was calibrated per manufacturer recommendations prior to each session. Following calibration, the tether was adjusted to participant height. The power output was measured by the NMT software (Pacer Performance System, XPV7 2.1.14, O'Neill Associates, Adelaide, Australia) as the product of horizontal force and velocity of the belt. The sampling rate was set at 200 Hz with cut-off filters for distance,

velocity, acceleration, horizontal force, vertical force, and center of pressure set at 50 Hz. Sprint kinetic and kinematics were analyzed as the averages of individual steps calculated by the software's gait analysis function.
Force-velocity Tests: Familiarization and force-velocity optimization occurred during V1. Due to the upright and weight-bearing nature of running, NMT familiarization and force-velocity test were performed first, followed by the CE.

Familiarization-NMT*:* A standardized NMT-specific warm-up was performed which consisted of a 3-minute walk, followed by two 30-second jogs at a self-selected velocity with zero load. Each jog was separated by 30-seconds of passive rest. After the jogging period, participants were allotted 5-minutes to passively recover. Participants were then instructed to perform five 3- to 5-second accelerations at varying intensities with 30-seconds of rest in between the trials. In order to learn the forward leaning technique needed to propel the treadmill, practice accelerations were performed with loads of decreasing resistances of 13.6, 11.4, 9.1, 6.8, and 4.5 kg for males and 11.4, 9.1, 6.8, 4.5, and 2.3 kg for females. The last acceleration warm-up trial (4.5kg male, 2.3kg female) was performed at 100% of perceived maximal velocity. Following the warmup, a 5-minute passive rest was provided.

Force-velocity-NMT: The multiple-trial force-velocity test involved five to six 5-second maximum effort sprints against increasing relative braking forces of 5%, 10%, 15%, 20%, 25%, and 30% of participant body mass (BM) with 5-minutes of passive rest between each sprint trial. Pilot testing revealed that relative braking force in this population should not exceed 30% BW due to an inability to achieve a flight-phase leading to alterations in running mechanics. Five-seconds was selected for the duration of the sprints as peak velocity has been shown to be achieved during this time (13,14). Data averaged across individual steps during the 5-second sprints, were recorded and exported into Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA) for further analysis. Sprinting data was averaged over three full sprint stride cycles (3 strides = 6 steps). Individualized optimal resistance was selected as the setting where the highest 3-stride average PP was produced by the participant.

Familiarization-CE: After a minimum 5-minute passive recovery from the NMT force-velocity test, the participants were fitted on the CE for handlebar, saddle height and forward placement, which was recorded and repeated for either V2 or V3. A standardized modality-specific warm-up was performed on the CE which consisted of 5-minutes of pedaling at 60 RPM against 50 W, interspersed with 3- to 5-second maximal accelerations at the 3rd and 4th minute.

Force-velocity-CE: The force-velocity test on the CE involved five full effort 10-second sprints to maximum velocity and five minutes of passive recovery was provided after each effort. The participants were then given instructions on the stationary starting procedure (dominant foot set at approximately 30-degrees) and were then instructed to start pedaling with full effort while remaining seated. Sprints were performed in an increasing order of torque factors: 0.4 Nm/kg, 0.6 Nm/kg, 0.8 Nm/kg, 1.0 Nm/kg, and 1.2 Nm/kg. Raw data was exported into Microsoft Excel for further analysis. Performance data was analyzed in successive 3-revolution averages.

Peak power for each trial was defined as the highest 3-revolution average power output. Optimal torque factor was selected as the torque factor producing the highest PP output.

30-second Anaerobic Power Tests: Upon arrival for the 30-second tests on V2 or V3 depending on randomized assignment, participant body mass was recorded prior to being fitted with a Polar heart rate monitor (Polar Electro Oy, Kempele, Finland). For CE WAnT, participants performed the same cycle-specific warm-up as during the familiarization session during V1. After a 5-min passive rest, participants were instructed to start the anaerobic power test from the stationary start at their optimal resistance. The test was initiated upon a verbal prompt and participants pedaled at maximal velocity while encouraged to maintain full effort and remain seated until the end of the test. Verbal encouragement was limited to "go" and "keep going" accompanied by clapping.

For the NMT 30-second test on V2 or V3 depending on randomized assignment, participants performed the treadmill-specific warm-up followed by a five-minute passive rest. After being clipped into the horizontal load-cell, the participants were then instructed to assume a forward-leaning start position while the treadmill belt was physically braked by the chief investigator's foot. The test initiated upon a verbal prompt and participants began a maximal effort 30-second sprint with the pre-determined resistance and were encouraged throughout the 30-second test.

Upon test termination, peak heart rate (HR_{peak}) and rating of perceived exertion (RPE) were taken, and 1-minute following test termination blood lactate (BLa^-) was taken using a portable lactate analyzer (Nova Biomedical Lactate Plus, Waltham, MA, USA). Following the BLa^- measurement participants completed a self-selected cool-down. For both tests, PP was defined as the highest 5-second average interval of instantaneous power output, MP as the average of the 30-second power output, and FI was calculated as the percent decline from highest to the lowest 5-second average interval. Participants were surveyed 24-72 hours after the final trial in regards to their preference of 30-second anaerobic test modality.

Statistical Analysis

Data were analyzed using SPSS 25.0 for Windows (IBM, SPSS Statistics, Armonk, NY, USA). Power measures were reported as 5-second averages and expressed in Watts (W). Ratio-scaled power values were expressed relative to BM (W/kg). One-way analysis of variance (ANOVA) was used to compare all performance indices, HR_{max}, BLa^-, and RPE by modality. Sex differences for optimal CE torque factor, NMT optimal resistance, HR_{max}, BLa^-, and RPE were also analyzed by one-way (ANOVA). Pearson product moment correlation coefficients were used to assess strength of association between modalities. The magnitude of the effect size (ES) was determined by Hopkins' scale (11) as follows: 0-0.2 = trivial, 0.3-0.6 = small, 0.7-1.2 = moderate, 1.3-2.0 = large, >2.0 = very large. The following thresholds were used to describe the *r* values: 0 to 0.30 small, 0.31 to 0.49 moderate, 0.50 to 0.69 large, 0.70 to 0.89 very large, and 0.90 to 1.00 near perfect (11). Alpha level was set at 0.05 for all analyses.

RESULTS

Force-velocity testing resulted in average CE optimal torque factor of 0.70 ± 0.17 Nm/kg for the entire sample with males having a higher optimal torque factor than females (0.78 ± 0.16 Nm/kg vs. 0.62 ± 0.14 Nm/kg respectively, P = 0.001). Optimal braking force on the NMT was 15.48 ± 3.99% BW, with no significant differences between males and females (16.65 ± 4.49% BW and 14.30 ± 3.10% BW respectively, P = 0.061).

Results of the comparison between CE WAnT and NMT 30-second power test performance and physiological indices for the entire sample are reported in Table 1. Absolute and relative PP, MP, and FI were significantly higher with the CE (P < 0.05) with small ES. However, HR_{max}, BLa^- and RPE were higher with the NMT (P < 0.05) with small to moderate ES.

Table 1. Power output and fatigue measures between CE WAnT and NMT 30-second maximal effort test for entire sample (N = 40). Values are represented as mean ± standard deviation.

	CE WAnT	95%CI	NMT 30-s Test	95%CI	Cohen's d	P-value
PP (W)	862.4 ± 235.9	789.3 - 935.5	747.6 ± 227.3	677.2 - 818.0	0.50	< 0.001*
PP_{rel} (W/kg)	11.9 ± 2.0	11.3 - 12.5	10.2 ± 2.1	9.5 - 10.9	0.83	< 0.001*
MP (W)	622.1 ± 181.5	565.9 - 678.3	576.3 ± 165.7	525.0 - 627.7	0.26	< 0.001*
MP_{rel} (W/kg)	8.5 ± 1.6	8.0 - 9.0	7.9 ± 1.6	7.4 - 8.4	0.38	< 0.001*
FI (%)	49.6 ± 6.6	47.6 - 51.6	45.4 ± 8.2	42.9 - 47.9	0.56	= 0.001*
HR_{max} (bpm)	176.2 ± 9.1	173.4 - 179.0	182.7 ± 9.0	179.9 - 185.5	0.72	< 0.001*
BLa^- (mmol/L)	10.9 ± 2.2	10.2 - 11.6	12.2 ± 2.5	11.4 - 13.0	0.55	< 0.001*
RPE	17.5 ± 2.1	16.8 - 18.2	18.1 ± 1.8	17.5 - 18.7	0.31	= 0.014*

PP = peak power, PP_{rel} = peak power relative to body mass, MP = mean power, MP_{rel} = mean power relative to body mass, FI = fatigue index, HR_{max} = maximum heart rate, Bla^- = blood lactate, RPE = rate of perceived exertion. * indicates significant difference between modalities (P ≤ 0.05).

Sex specific results are reported in Tables 2 and 3. Both sexes produced significantly higher absolute and relative PP and MP on the CE compared to NMT (P < 0.05) with moderate ES for PP and small ES for MP. No statistically significant differences were found in FI among males between CE and NMT (P = 0.201), whereas females showed significantly higher FI on CE (P = 0.002) with a moderate ES. Post-test HR_{max} was significantly higher after NMT trial (P < 0.05) with moderate ES. BLa^- was also significantly higher after NMT trial (P < 0.05) with small ES observed for males and moderate ES for females.

When both CE and NMT 30-second tests were compared as 5-second average intervals, males showed a significant difference in the 5-10 second and 25-30 second segment, whereas females had a significant difference in the 0-5 second (P < 0.001) and 5-10 second (P < 0.001) segments, with CE producing greater power output compared to NMT at these time points (Figure 1).

Lastly, when broken down by sex, 20% of females and 15% of males preferred CE, while 75% of females preferred the NMT compared to 60% of males with 5% of females and 25% of males indicating no preference for either modality.

Table 2. Power output and fatigue measures between CE WAnT and NMT 30-second maximal effort test for males (N = 20). Values are represented as mean ± standard deviation.

	CE WAnT	95%CI	NMT 30-s Test	95%CI	Cohen's d	P-value
PP (W)	1054.9 ± 155.9	986.6 - 1123.2	944.1 ± 120.5	891.3 - 996.9	0.80	< 0.001*
PP_{rel} (W/kg)	13.2 ± 1.4	12.6 - 13.8	11.8 ± 1.4	11.2 - 12.4	1.0	< 0.001*
MP (W)	766.5 ± 128.3	710.3 - 822.7	721.0 ± 85.2	683.7 - 758.3	0.42	0.024*
MP_{rel} (W/kg)	9.6 ± 1.2	9.1 - 10.1	9.0 ± 1.1	8.5 9.5	0.52	0.024*
FI (%)	50.9 ± 6.1	48.2 - 53.6	49.0 ± 6.7	46.1 - 51.9	0.30	0.201
HR_{max} (bpm)	174.3 ± 7.9	170.8 - 177.8	181.7 ± 9.6	177.5 - 185.9	0.84	< 0.001*
Bla^- (mmol/L)	11.6 ± 2.4	10.5 - 12.7	12.7 ± 2.9	11.4 - 14.0	0.41	0.027*
RPE	17.8 ± 2.0	16.9 - 18.7	18.5 ± 1.8	17.7 - 19.3	0.37	0.059

PP = peak power, PP_{rel} = peak power relative to body mass, MP = mean power, MP_{rel} = mean power relative to body mass, FI = fatigue index, HR_{max} = maximum heart rate, Bla^- = blood lactate, RPE = rate of perceived exertion * indicates significant difference between modalities (P ≤ 0.05).

Table 3. Power output and fatigue measures between CE WAnT and NMT 30-second maximal effort test for females (N = 20). Values are represented as mean ± standard deviation.

	CE WAnt	95%CI	NMT 30-s Test	95%CI	Cohen's d	P-value
PP (W)	670.0 ± 109.2	622.1 - 717.9	551.0 ± 101.1	506.7 - 595.3	1.13	< 0.001*
PP_{rel} (W/kg)	10.5 ± 1.5	9.8 - 11.2	8.6 ± 1.45	8.0 - 9.2	1.27	< 0.001*
MP (W)	477.6 ± 85.2	440.3 - 514.9	431.7 ± 71.3	400.5 - 462.9	0.58	< 0.001*
MP_{rel} (W/kg)	7.5 ± 1.1	7.0 - 8.0	6.8 ± 1.0	6.4 - 7.2	0.67	< 0.001*
FI (%)	48.2 ± 6.9	45.2 - 51.2	41.7 ± 8.2	38.1 - 45.3	0.86	0.002*
HR_{max} (bpm)	178.2 ± 10.0	173.8 - 182.6	183.8 ± 8.5	180.1 - 187.5	0.60	0.033*
Bla^- (mmol/L)	10.3 ± 1.9	9.5 - 11.1	11.7 ± 2.1	10.8 - 12.6	0.70	0.004*
RPE	17.2 ± 2.2	16.2 - 18.2	17.7 ± 1.7	17.0 - 18.4	0.25	0.131

PP = peak power, PP_{rel} = peak power relative to body mass, MP = mean power, MP_{rel} = mean power relative to body mass, FI = fatigue index, HR_{max} = maximum heart rate, Bla^- = blood lactate, RPE = rate of perceived exertion. * indicates significant difference between modalities (P ≤ 0.05).

DISCUSSION

The primary purpose of this study was to compare the 30-second WAnT performed on a CE to a 30-second maximal effort test performed on a NMT under standardized conditions and optimal resistance. Key findings of this study revealed that absolute and relative PP, MP, and FI were higher on the CE compared to NMT, with HR_{max}, BLa^-, and RPE being higher with the NMT. Females had a higher FI on the CE compared to NMT, whereas males showed no significant difference. Despite the NMT 30-second test resulting in higher HR_{max} and post-test BLa^-, sex specific comparison did not show a difference in RPE between the two modalities within males or females. All variables were significantly correlated among male participants, whereas females did not show a significant correlation in FI and HR_{max}.

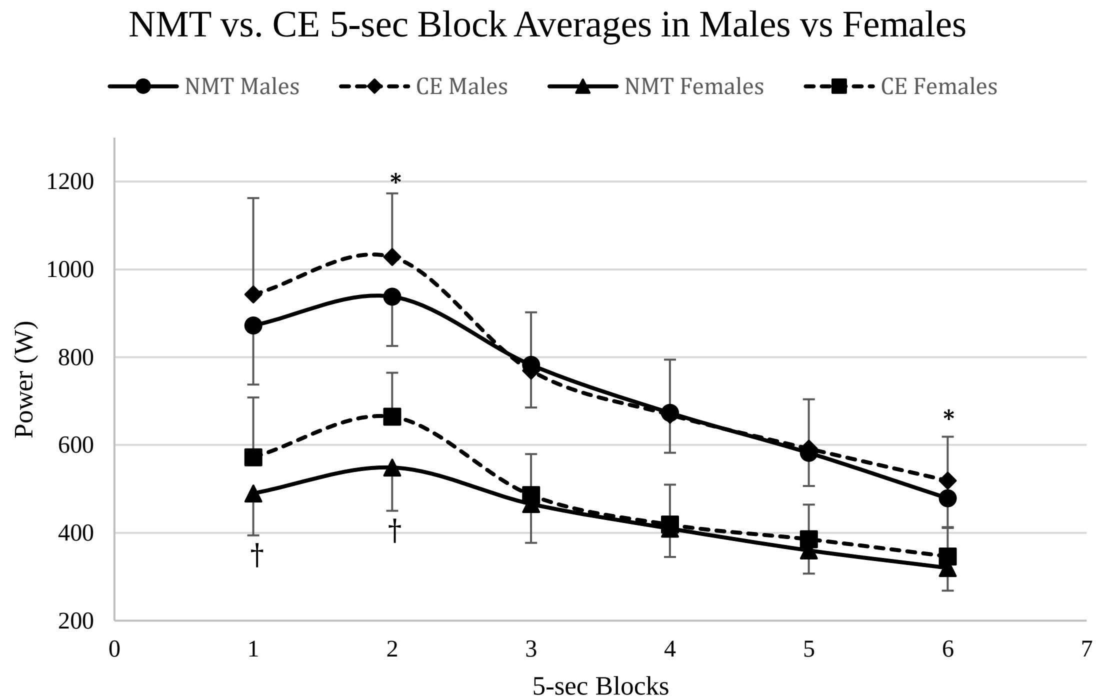

Figure 1. Five-second block averages between CE and NMT among males and females.
* indicates significant difference between modalities among males ($P \leq 0.05$).
† indicates a significant difference between modalities among females ($P \leq 0.05$).

Optimal Measures- This study sought to normalize loads experienced by participants through the optimization of individual peak force production, optimal torque for the CE and optimal resistance for the NMT. Mean optimal torque for achieving PP was 0.70 Nm/kg for the group, 0.78 Nm/kg for males, and 0.62 Nm/kg for females. The findings of this study are comparable to the Lode software's default settings of 0.70 Nm/kg for males and 0.67 Nm/kg for females. However, Wiedemann et al. found male participants to have a mean optimal torque factor of 1.13 Nm/kg with the same ergometer used in this study (29), which is in agreement with optimal resistances found on mechanically braked cycle ergometers, ranging from 0.84 – 1.22 $N \cdot kg^{-1}$ (12,17,18,28,29). To our knowledge, this is the first study to use revolution average power output values for the determination of optimal resistance on an electromagnetically braked cycle ergometer, which is likely the reason optimal values are lower than previously reported.

For the NMT, mean optimal resistance for PP was 15% of BW for the group with 17% for males and 14% for females. This is in agreement with McLain et al. who found 18% BW resistance to produce the highest PP during a maximal 25-second anaerobic power test (19). In contrast, Andre et al. conducted a similar force-velocity test using the same NMT and found optimal resistance to be 35% BW in physically active males (1). However, it is possible that participants produced higher power outputs at higher resistances due to a learning effect taking place throughout the trials, whereas pilot data in our lab demonstrated an inability to achieve a flight-phase leading to alterations in running mechanics.

Peak Power and Mean Power- The CE WAnT produced a higher PP and MP compared to the NMT for the group as well as for males and females separately. The 5-second averages of the 30-second tests revealed a very similar pattern between both modalities, with the biggest difference originating from the first 10-seconds of the test (Figure 1). For males, the CE produced a significantly greater 5-second average power output for segment two (5-10 seconds) and segment six (25-30 seconds), with no differences between the other segments. Among females, CE produced greater power output for segment one and two (0-5 seconds, 5-10 seconds), with no differences between the rest of the 5-second average segments. Our findings are in agreement with Chia and Lim, who found 10-second MP to be significantly greater on a mechanically braked CE compared to a sprint treadmill (3). However, they reported PP as a 1-second average to be significantly greater on the NMT for both males and females. The authors used the traditional CE flywheel resistance of 0.74 $N \cdot kg^{-1}$ and speculated that PP on the NMT was due to the flywheel resistance not being optimized for PP production. Our findings support this theory as resistance was optimized for PP across both devices with the CE producing greater PP output compared to the NMT test. In contrast, Falk et al. compared a 20-second treadmill sprinting protocol to that of a traditional 30-second cycle protocol and found treadmill power outputs to be higher compared to the cycle ergometer, hypothesizing that the weight bearing component of sprinting produces superior power outputs compared to cycling (7). These discrepancies may exist because Falk et al. reported NMT power as the sum of its horizontal and vertical component, and they compared trained youth athletes on the NMT to active youths on the CE, which may explain why all power indices were higher on the NTM in their investigation.

Aside from cycling being performed in a seated position with neutral gravity loading and involving lower body musculature, running is load-bearing and involves whole-body musculature. The greater mechanical power output on CE compared to NMT may also be explained by their kinetic and kinematic differences. Evidence suggests that impulse may be a better measure of anaerobic performance than mechanical power when using treadmill sprinting (3). Frequent alterations of push-off and flight phase during sprinting cause large fluctuations of velocity and horizontal force within a stride-cycle, resulting in approximately 80% drop in peak values during the flight phase using NMTs (15). Over an extended interval, such as 5-seconds for PP and 30-seconds for MP, this recurring drop in force and velocity may result in a lower power value compared to CE. During cycling, each push on the pedal is immediately followed by the next, leaving no time for force or velocity to approach zero as it does during NMT sprinting. This was demonstrated by Gonzales et al. who compared a 30-second anaerobic capacity test on a curved NMT and CE, showing instantaneous PP to be significantly higher on the NMT (8). However, MP was more than double the wattage shown on the CE compared to the curved NMT.

Fatigue Index- Studies using the same CE and NMT as the current investigation have reported similar FI values with Jaafar et al. reporting a FI of 46.8 ± 4.6% among recreationally trained participants during a CE WAnT at 8.7% BW resistance (12) and McLain et al. reporting 51.7 ± 9.3% among collegiate male athletes during a 25-second anaerobic power test on a NMT at 18% BW resistance (19). However, to our knowledge none have compared FI indices among males and females between CE and NMT anaerobic power tests. In the current study, FI was higher on the CE when compared to the NMT for the entire sample. However, sex specific FI did not significantly differ between the two tests among males, while females had a significantly higher FI with CE WAnT when compared to the NMT. This suggests that females may have had a pacing strategy during the NMT sprint test. Another possible explanation could result from females not generating large amounts of power at the start of the test, which could have resulted in the ability to maintain power output throughout the duration of the NMT test.

HR, BLa^- and RPE- Maximum heart rate, BLa^-, and RPE were all significantly higher following the NMT bout when compared to CE over the entire sample. Interestingly, the significance in RPE was lost when data were separated into males and females, while HR_{max} and BLa^- remained lower on the CE for both sexes. The elevated HR_{max} and BLa^-, are likely the result of total muscle recruitment involved in the NMT versus that of the CE. Generally, the more muscle recruited during exercise results in the greater demand on the distribution of blood, which requires an increase in cardiac output and therefore HR (23). This same phenomenon can also explain the increase in BLa^-, with more fatiguing muscle, the likelihood of BLa^- production goes up (25). Research has shown that the perception of discomfort is much greater in runners completing an incremental cycle exercise than cyclists performing a running-based test (21). It could be hypothesized that our recreationally active participants were naturally more comfortable with running and thus did not perceive it to be much harder than the cycling test, even though the NMT test resulted in a significantly higher HR_{max} and BLa^- concentration. Though we did not measure the clearance of BLa^-, the NMT group may have experienced a more rapid clearance due to the increased recruitment of muscle, which could have altered participants' perception of the trial.

Additionally, 75% of the females and 60% of the male participants preferred the NMT version of the 30-second all-out test as evidenced by a post-test survey, despite the increased RPE. Though participants did not provide a reason for their preference, it may be as simple as more familiarity with sprinting versus all-out effort on the CE. The preference findings are interesting because maximal 30-second NMT testing has previously resulted in difficulties finishing the test, which could likely be due to the weight-bearing balance component involved in sprint-running and fear of falling (7,19). This has led researchers to opt for shorter (10 to 25-second) protocols when using sprint treadmills (3,7,19). The current findings suggest that utilizing the Woodway Force NMT could be a viable and preferred option for the full 30-second anaerobic power test among recreationally active males and females when loads are optimized.

Though the current study was carefully designed and executed, there were limitations. First, there was minimal familiarization before the force-velocity test which could have resulted in a learning effect and may have affected the optimized power (5,8,9). The CE force-velocity test duration was 10 seconds and may have inadvertently induced fatigue throughout the test and should be reduced to 8 seconds in the future. Additionally, one-minute post-test lactate measurement, over the traditional 4- to 5-minute post-test sampling, was used in order to get a measurement prior to the self-selected cool-down. Thus, BLa^- measures cannot be reported as peak values. Future studies should extend La- and HR measures beyond the one-minute post trial. Finally, the sample was fairly homogenous in terms of age and activity level making it difficult to generalize findings to a broader audience; however, recreationally active individuals were selected as to avoid highly trained individuals accustomed to either modality.

Conclusion: The current study showed that 30-second WAnT produces higher PP and MP on CE compared to NMT among both males and females. Power output 5-second intervals showed the two tests to follow very similar patterns with the first 10-seconds of each test producing the greatest difference between the modalities. Non-motorized treadmill maximal 30-second test produced higher HR_{max} and post-test BLa^{-}, although was not perceived as a harder test and was generally preferred over the CE by both male and female participants. However, caution should be taken when testing recreationally trained females due to the inconsistencies in FI and HR_{max} compared to their male counterparts. Overall these tests for anaerobic power, performed with optimized loads, produced different results for several variables and these modalities should not be considered interchangeable. Therefore, practitioners should consider which modality best mimics the activities of the person being tested when selecting a protocol. Future research should examine this protocol in various sprint-based athletes to assess their appropriateness for determining anaerobic power.

REFERENCES

1. Andre MJ, Fry AC, Lane MT. Appropriate loads for peak-power during resisted sprinting on a non-motorized treadmill. J Hum Kinet 38: 161–7, 2013.

2. Bar-Or O. The Wingate Anaerobic Test An update on methodology, reliability and validity. Sports Med 4(6): 381–94, 1987.

3. Chia M, Lim JM. Concurrent validity of power output derived from the non-motorised treadmill test in sedentary adults. Ann Acad Med Singap 37(4): 279-85, 2008.

4. Dotan R. The Wingate Anaerobic Test's past and future and the compatibility of mechanically versus electro-magnetically braked cycle-ergometers. Eur J Appl Physiol 98(1): 113–6, 2006.

5. Driss T, Vandewalle H. The measurement of maximal (anaerobic) power output on a cycle ergometer: A critical review. BioMed Res Int 2013: e589361, 2013.

6. Earnest CP, Wharton RP, Church TS, Lucia A. Reliability of the Lode Excalibur sport ergometer and applicability to Computrainer electromagnetically braked cycling training device. J Strength Cond Res 19(2): 344-8, 2005.

7. Falk B, Weinstein Y, Dotan R, Abramson DA, Mann-Segal D, Hoffman JR. A treadmill test of sprint running. Scand J Med Sci Sports 6(5): 259–64, 1996.

8. Gonzalez AM, Wells AJ, Hoffman JR, Stout JR, Fragala MS, Mangine GT, et al. Reliability of the Woodway Curve™ non-motorized treadmill for assessing anaerobic performance. J Sports Sci Med 12(1): 104–8, 2013.

9. Highton JM, Lamb KL, Twist C, Nicholas C. The reliability and validity of short-distance sprint performance assessed on a nonmotorized treadmill. J Strength Cond Res 26(2): 458-65, 2012.

10. Hopker JG, Coleman DA, Wiles JD, Galbraith A. Familiarisation and reliability of sprint test indices during laboratory and field assessment. J Sports Sci Med 8(4): 528–32, 2009.

11. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 41(1): 3–13, 2009.

12. Jaafar H, Rouis M, Attiogbé E, Vandewalle H, Driss T. A comparative study between the Wingate and force–velocity anaerobic cycling tests: Effect of physical fitness. Int J Sports Physiol Perform 11(1): 48–54, 2016.

13. Jaskólska A, Goossens P, Veenstra B, Jaskólski A, Skinner JS. Comparison of treadmill and cycle ergometer measurements of force-velocity relationships and power output. Int J Sports Med 20(3): 192–7, 1999.

14. Jaskólski A, Veenstra B, Goossens P, Jaskólska A, Skinner JS. Optimal resistance for maximal power during treadmill running. Sports Med Train Rehabil 7(1): 17–30, 1996.

15. Lakomy HKA. The use of a non-motorized treadmill for analysing sprint performance. Ergonomics 30(4): 627–37, 1987.

16. Legaz-Arrese A, Munguía-Izquierdo D, Carranza-García LE, Torres-Dávila CG. Validity of the Wingate Anaerobic Test for the evaluation of elite runners. J Strength Cond Res 25(3): 819-24, 2011.

17. Linossier M-T, Dormois D, Fouquet R, Geyssant A, Denis C. Use of the force-velocity test to determine the optimal braking force for a sprint exercise on a friction-loaded cycle ergometer. Eur J Appl Physiol 74(5): 420–7, 1996.

18. MacIntosh BR, Rishaug P, Svedahl K. Assessment of peak power and short-term work capacity. Eur J Appl Physiol 88(6): 572–9, 2003.

19. McLain TA, Wright GA, Camic CL, Kovacs AJ, Hegge JM, Brice GA. Development of an anaerobic sprint running test using a nonmotorized treadmill. J Strength Cond Res 29(8): 2197-204, 2015.

20. Medbo JI, Tabata I. Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. J Appl Physiol 67(5): 1881–6, 1989.

21. Millet GP, Vleck VE, Bentley DJ. Physiological differences between cycling and running. Sports Med 39(3): 179–206, 2009.

22. Minahan C, Chia M, Inbar O. Does power indicate capacity? 30-s Wingate Anaerobic Test vs. maximal accumulated O2 deficit. Int J Sports Med 28(10): 836–43, 2007.

23. Mortensen SP, Svendsen JH, Ersbøll M, Hellsten Y, Secher NH, Saltin B. Skeletal muscle signaling and the heart rate and blood pressure response to exercise. Hypertension 61(5): 1126-33, 2013.

24. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1–8, 2020.

25. Sahlin K. Muscle fatigue and lactic acid accumulation. Acta Physiol Scand Suppl 556: 83–91, 1986.

26. Simperingham KD, Cronin JB, Ross A. Advances in sprint acceleration profiling for field-based team-sport athletes: Utility, reliability, validity and limitations. Sports Med 46(11): 1619–45, 2016.

27. Sweeney KM, Wright GA,Brice AG, Doberstein ST. The effect of β-alanine supplementation on power performance during repeated sprint activity. J Strength Cond Res 24(1): 79-87, 2010.

28. Vargas NT, Robergs RA, Klopp DM. Optimal loads for a 30-s maximal power cycle ergometer test using a stationary start. Eur J Appl Physiol 115(5): 1087–94, 2015.

29. Wiedemann MSF, Bosquet L. Anaerobic work capacity derived from isokinetic and isoinertial cycling. Int J Sports Med 31(2) 89–94, 2010.

30. Zajac A, Jarzabek R, Waskiewicz Z. The diagnostic value of the 10− and 30-second Wingate test for competitive athletes. J Strength Cond Res 13(1): 16-9, 1999.

31. Zemková E, Hamar D. "All-out" tethered running as an alternative to Wingate anaerobic test. Kinesiology 36(2.): 165–72, 2004.