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Wingate normative-reference values for a large cohort of Canadian university students

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Abstract

Study aim: The Wingate Anaerobic Test evaluates anaerobic power and capacity. Used to assess performance, historically among athletic populations, its evaluative capacity for individuals of varying athletic abilities is limited by a lack of normative data based on large participant populations. This study developed Wingate normative-reference values based on a large-scale cohort that is representative of the Canadian university student population.

Material and methods: Data were collected from 872 participants, aged 20 to 29 years (mean body mass index [BMI]: 24.44 kg/m^2). Testing was completed on a cycle ergometer using a widely recognized protocol, with resistance set at 7.5% of participants'. An independent samples t-test was used to compared the means of dependent variables (i.e., peak power [PP], mean power [MP], and fatigue index [FI]) and test for statistical significance ($p < 0.05$) between sexes, and Cohen's d determined effect size.

Results: Males had higher PP and MP (W and W · kg^{-1}), whereas females exhibited lower FI (%). Statistically significant differences between sexes were observed for all variables.

Conclusions: Collected data yielded normative-reference standards, including percentile rankings and performance classifications. These norms will allow for significant practical applications, including an effective method to assess anaerobic performance and health.

Key words: Anaerobic test – Fatigue index – Peak power – Mean power – Anaerobic power – Anaerobic capacity

Introduction

The Wingate Anaerobic Test (herein: Wingate) is an exercise protocol, performed using a cycle ergometer, that is designed to test anaerobic power and capacity. To date, no universally accepted standardized Wingate testing protocol exists [13]. Typically, the Wingate consists of two, 30-second bouts of maximal pedaling against a constant braking force equivalent to 7.5% of participant's body mass (BM) in kilograms (kg) [2]. The braking force induces fatigue within the first few seconds of the protocol, resulting in a drop in mechanical power [31]. The two pedaling bouts are separated by a 30-second resting period, during which the braking force is removed, and participants can pedal at a self-determined pace. Wingate testing allows for the assessment of anaerobic capabilities, including mean power (MP) generated during each 30-second bout [2, 13, 40], and peak power (PP) and fatigue index (FI), which represent the highest power generated from any five-second period, and the percent drop in power output across the bout, respectively [13, 31, 40].

The Wingate is a standard assessment of anaerobic performance [10, 13, 31], with its simplicity, reliability, and validity establishing its position as a valuable research tool [3, 10, 12, 37, 38]. Despite these advantages, its evaluative capacity for athletics and general health standards is limited by a lack of established normative values based on large participant populations [2, 11, 35, 39]. Among athletic and general populations [2, 11, 36, 40], developing normative-reference values could be useful for preliminary diagnostic purposes and to chart improvements throughout training [11]. Moreover, normative values could serve as health indicators and prompts to improve anaerobic fitness. This is especially important, as anaerobic fitness is a key component of physical fitness, and

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there exists a strong correlation between anaerobic fitness and daily functional ability [27]. This notion is reflected in several studies that have used the Wingate to assess health, functional ability, and physical fitness in young individuals (i.e., children and adolescents) with juvenile idiopathic arthritis [27, 39]. Results from the literature suggest that anaerobic fitness is necessary to perform everyday activities that are short-duration and more intensive in nature, such as climbing the stairs [27, 33, 39]. It is therefore evident that poorer anaerobic fitness can considerably impact daily functioning, making tasks more difficult to perform [27, 33, 39]. Poor anaerobic fitness is also associated with worse exercise behaviour and levels of physical activity, thus consequently impacting overall fitness and health [27, 33, 39]. A need to improve fitness may help identify individuals at a higher risk for a variety of diseases, such as coronary heart disease and cancer [14, 23, 35]. This concept is further reinforced by the fact that physical inactivity [5] and sedentary behaviour [20, 23, 35] are correlated with numerous negative health outcomes (e.g., increased risk of coronary heart disease [35], hypertension [20], etc.). It is also important to note that during Wingate testing, there is contribution from both the aerobic and anaerobic metabolic systems [4, 17, 29]. Whether an individual is more power or endurance inclined will be reflected in the metabolic system that is predominantly used to provide energy during the test [17, 29]. Additionally, there is a strong correlation between anaerobic (i.e., peak and mean power as determined by Wingate testing) and aerobic (i.e., absolute and relative peak maximal oxygen consumption values) indices [27]. Anaerobic power quantified by Wingate testing has also been found to be strongly correlated with body composition, specifically with fat free mass and muscle mass [8, 24, 25, 31]. Taken together, the above information suggests that, especially given its safety and simplicity, the Wingate is a valuable tool that can be used to non-invasively assess and quantify muscle performance, exercise capacity, and fitness [10, 27, 34]. Utilizing Wingate testing as an athletic and health indicator is further bolstered by the fact that its equipment can be relatively inexpensive and simple to use for analysis in different population demographics [10, 34].

To date, research has focused on assessing the validity of the Wingate [26, 34], appropriate braking force [13, 22], shortened protocols [18, 19, 38] and the effects of stretching [13, 15], caffeine intake [1, 16], and different recovery intervals [21] on performance. Few studies have focused on developing Wingate normative-reference values based on large participant populations [36], and instead, have selected a narrowed approach, such as analyzing and developing values [2, 5, 6, 11, 28, 30, 32, 40] and performance-based classification systems [40] for specific collegiate and intercollegiate athletic male [10, 30, 40] and female [2, 40] populations. In comparison to highly-trained male athletes, and consistent with previously recognized patterns in the Wingate literature, females tend to score lower on PP and MP, even when data are normalized to body mass [2, 28, 32, 36, 40]. For FI values, contradicting findings have been reported in the literature when comparing the data of athletic and non-athletic populations [2, 11, 30, 36]. These inconsistencies further support the need for the development of normative-reference standards for the general population. This will, in turn, provide a feasible and practical approach for non-athletic populations, thus allowing for the comparison of test results with data that are more demographically representative.

Non-athletic populations have seldom been a focus of study in the Wingate literature. Ramírez-Vélez et al. [36] developed normative-reference values and percentile rankings for a large scale non-athletic Columbian population (1,844 healthy adults aged 20 to 80 years), thus providing a more accurate representation of the general populace [36]. This cohort was distinctively selected for study because of the absence of Wingate data and normative-reference standards specific to the general Latin American population, in addition to the fact that no standardized Wingate protocol had been previously implemented for testing and data acquisition [36]. Basist [5] constructed normative-reference standards and percentile rankings that were more representative of the broader active and healthy young adult population through conducting Wingate testing on 330 exercise-trained participants aged 19 to 29 years. During testing, male and female participants pedaled against a resistance equal to 8.5% and 7.5% of their BM in kg, respectively [5]. Both studies reported a pattern of higher PP (watts [W]) and MP (W) among males [5, 36]. Also, when power was normalized to BM in kg, despite there still being statistically significant differences between sexes, there was a smaller discrepancy between male and female values [5, 36]. Many of these findings remain consistent with the results from previous studies [28]. Despite the comprehensive nature of the above-mentioned norms, results remain limited in terms of generalizability due to the specificity of the studies' populations (i.e., Columbia natives [36] and exercise-trained individuals [5]) and, consequently, cannot be validly generalized to other populations. The purpose of the present study was to further advance existing research and develop Wingate norms based on a large-scale, healthy, Canadian university student population with varying levels of athletic or non-athletic abilities, therefore more representative of the general Canadian young adult population.

Materials and methods

A total of 872 participants volunteered to participate in Wingate testing, using a widely recognized protocol (i.e., two, 30-second bouts of maximal pedaling, separated by

a 30-second resting period, with resistance set at 7.5% of the participant's BM in kg). The Monark Anaerobic Test Software (MAnTS) was used to record participants' PP, MP, and FI. Participants' values were analyzed for statistically significant differences ($p < 0.05$) and to develop Wingate normative-reference values, percentile rankings, and performance classifications for both sexes.

Participants

Participants were students at a Canadian university. Data were collected across eight semesters spanning nine years (Fall 2010 to 2019) using a convenience sample, as the inclusion criterion was enrollment in a Physiology course (n = 988; of which 41 either declined participation, were absent, or were injured). After exclusions (described below in Statistical analyses), 872 university-aged males (n = 396) and females (n = 476) aged 20 to 29 years completed Wingate testing. The sample's mean BM was 72.31 ± 14.63 kg (males: 81.22 ± 13.01 kg, females: 64.90 ± 11.43 kg), mean height was 171.56 ± 9.99 centimeters (cm) (males: 179.33 ± 7.38 cm, females: 165.10 ± 6.76 cm), and mean body mass index (BMI) was 24.44 ± 3.75 kg/m^2 (males: 23.27 ± 3.28 kg/m^2, females: 22.14 ± 3.51 kg/m^2).

The sample consisted of individuals with varying levels of athletic ability and fitness status (although not specifically quantified). Participants completed the Get Active Questionnaire or Physical Activity Readiness Questionnaire [9] and signed institutionally cleared review board consent forms prior to participation. Emphasis was placed on performing several minutes of proper warm-up and cool-down to compensate for the exhaustive nature of the test. Exclusion criteria included injury, illness (i.e., respiratory ailments, etc.), or any other contraindications to exercise testing. The university's Research Ethics Board approved this study.

Protocol

Wingate testing was conducted on a Monark 894E Test Ergometer (Monark Sports and Medical; Vansbro, Sweden; length: 112.00 cm, handlebar width: 51.70 cm, support leg: 64.00 cm, handlebar height: 94.50 cm to 129.50 cm, saddle height: 78.00 cm to 110.50 cm, total unit mass: 65.00 kg), and the MAnTS was used to record and compute PP, MP, and FI data. Participants' BMs were measured with a Physician Mechanical Balance Beam Scale (Catalogue Number: 654450 KL).

Investigators were present at all times to ensure maximal safety. Additionally, participants were instructed to adhere to the procedures designed to promote optimal safety and performance during testing (e.g., refraining from consuming food and smoking tobacco two hours before testing, and being strongly advised to refrain from caffeine, alcohol, and strenuous exercise six hours before testing).

During the five-minute warm-up, the participant's full name, date of birth, sex, and BM were entered into the MAnTS. The Wingate basket attached to the Monark 894E Test Ergometer was loaded with weights equivalent to 7.5% of the participant's BM in kg, while accounting for the one kg mass of the basket. This resistance was used, as it was the load employed during the original Wingate test, which evaluated young participants who were close in age to the participants in the present study [3, 7, 10]. Additionally, 7.5% is a suitable resistance for testing a general population composed of individuals with varying levels of athletic and non-athletic abilities [3, 7, 10]. The height of the cycle ergometer's seat was adjusted so that the participant's legs extended just short of full extension, and the foot straps were tightened to secure the participant's feet in place.

Participants were instructed to perform their warm-up, without resistance, at a self-chosen rate slower than 100 revolutions per minute (rpm). During the last five seconds of the warm-up, participants were instructed to increase their cycling rate to a speed of greater than or equal to 100 rpm, activating the MAnTS to drop the weighted basket and begin recording the first 30-second bout of the test.

During the test, participants pedaled with maximal effort for the 30-second bout with the aid of verbal encouragement from investigators. Participants were instructed to remain seated throughout the duration of the test. After the first 30-second bout, the resistance provided by the weighted basket was lifted manually by an investigator and magnetically locked in the upward position. The MAnTS produced values for the participants' PP and MP, and FI (in W and W per kg [W · kg^{-1}], and percentage [%], respectively) based on the 30-second bout. A 30-second resting period was then provided, during which participants pedaled at a rate of their discretion (and less than 100 rpm) against minimal resistance. Subsequently, the same protocol was followed for the second, 30-second bout. Lastly, participants completed a proper cool-down, which lasted several minutes.

Statistical analyses

Prior to conducting the main statistical analyses, the data were assessed for abnormalities. Outliers in the raw data were included in the statistical analyses, provided that they were not deemed erroneous as a result of human or data entry error. Data were removed for reasons including missing data (55 participants), erroneous data (16 participants), and age (three participants [40+ years], as they were not representative of the studied population). Given that only one participant self-identified as non-binary, their data were not included for analyses. As a result, the final sample size was established (n = 872 participants, 396 males and 476 females). All statistical analyses were conducted using the IBM Statistical Package for the Social

Sciences (SPSS) software (version 28). Frequencies and descriptive statistics focused on the mean and standard deviation (SD) values generated for all variables. PP and MP values were provided in W and W · kg^{-1}, while FI was provided as a percentage. An independent samples t-test was conducted to compare the means of all three dependent variables (i.e., PP, MP, and FI) and to test for statistical significance ($p < 0.05$) between sexes, and Cohen's d was used to determine effect size. Finally, male and female Wingate performance classifications for PP and MP (W and W · kg^{-1}) and FI (%) were constructed. To create performance classifications, the ranges for both the raw PP data and their associated Z-scores were calculated using Microsoft Excel. The range was then divided by seven to generate seven classifications, a modification to the process employed by Zupan et al. [40]. Each classification was separated by equal raw data scores and Z-score increments. The Z-score range for female PP (W) was 7.85 (–3.45 to 4.41), meaning that each of the seven performance classifications was separated by 1.12 SDs. This value corresponded to equal raw data score categories of 170 W (since the raw data score range of 1,188 W was divided by seven). For example, 170 W was subtracted from the highest raw PP score recorded (1,249–170 W) to yield an 'elite' classification of >1,079 W. Likewise, 170 W was subtracted from 1,079 W to yield an 'excellent' classification of 909–1,079 W, and so on for the remainder of the classification categories. Male PP (W) had a Z-score range of 7.84 (–3.97 to 3.87), therefore, each classification was separated by 1.12 SDs. This value corresponded to equal raw data score categories of 233 W (since the raw data score range of 1,628 W was divided by seven). For example, 233 W was subtracted from the highest raw PP score recorded (1,743–233 W) to yield an 'elite' classification of >1,510 W. Likewise, 233 W was subtracted from 1,510 W to yield an 'excellent' classification of 1,277–1,510 W, and so on for the remainder of the classification categories. Performance classifications consisted of 'elite', 'excellent', 'above average', 'average', 'below average', 'fair', and 'poor', which is comparable to the method used by Zupan et al. [40]. The same procedure was utilized to create performance classifications for MP and FI.

Results

Table 1 displays the PP (W and W · kg^{-1}), MP (W and W · kg^{-1}), and FI (%) results from the first bout of Wingate testing. For the purposes of this study and comparison to the literature, only bout one values were analyzed. Overall, the assessment of Wingate results from the Canadian adult population revealed mean values for PP, MP, and FI of 744.43 ± 252.22 W (10.21 ± 2.29 W · kg^{-1}), 526.28 ± 162.84 W (7.21 ± 1.39 W · kg^{-1}), and 56.58 ± 9.52%, respectively. Yielded from the independent samples t-test, statistically significant differences were observed between sexes for PP in W ($p = 0.001$, $d = 1.96$) and W · kg^{-1} ($p = 0.001$, $d = 1.39$), MP in W ($p = 0.001$, $d = 2.15$)

Table 1. Wingate test results for Canadian young adult population (Bout 1)

Variable	sex	N	Mean ± SD	Minimum	Maximum
PP (W)	Males	396	939 ± 208	115	1,743
	Females	476	582 ± 151	61	1,249
	Total	872	744 ± 252	61	1,743
PP (W · kg^{-1})	Males	396	11.64 ± 1.95	3.88	18.21
	Females	476	9.02 ± 1.82	4.33	19.83
	Total	872	10.21 ± 2.29	3.88	19.83
MP (W)	Males	396	657 ± 125	341	1,126
	Females	476	417 ± 97	203	918
	Total	872	526 ± 163	203	1,126
MP (W · kg^{-1})	Males	396	8.13 ± 1.07	3.13	14.58
	Females	476	6.45 ± 1.15	3.35	12.84
	Total	872	7.21 ± 1.39	3.13	14.58
FI (%)	Males	396	57.34 ± 9.99	23.09	93.52
	Females	476	55.53 ± 8.98	23.09	88.04
	Total	872	56.58 ± 9.52	23.09	93.52

N – sample size; PP – peak power; MP – mean power; FI – fatigue index; W – watts, W · kg^{-1} – watts per kilogram.

and W · kg^{-1} (p = 0.001, d = 1.51), and FI (p = 0.001, d = 0.20) values. A pattern of higher PP (W and W · kg^{-1}) and MP (W and W · kg^{-1}) values among male participants was noted in comparison to female participants. The mean PP and MP values for males were 939 ± 208 W (11.64 ± 1.95 W · kg^{-1}) and 657 ± 125 W (8.13 ± 1.07 W · kg^{-1}), respectively, and for females were 582 ± 151 W (9.02 ± 1.82 W · kg^{-1}) and 417 ± 97 W (6.45 ± 1.15 W · kg^{-1}), respectively. Additionally, female participants tended to fatigue less easily compared to males, as evidenced by their lower FI scores (the mean scores for males and females were 57.34 ± 9.99% and 55.53 ± 8.98%, respectively). Seven male and female performance classifications ranging from 'poor' to 'elite' were constructed, which are displayed in Tables 2 and 3, respectively. Additionally, percentile rankings ranging from the 5th to 95th percentiles for male and female PP (W and W · kg^{-1}), MP (W and W · kg^{-1}), and FI (%) are presented in Tables 4 and 5, respectively. Descriptive statistics and frequencies in SPSS were used to create percentile rankings by computing intervals to determine every fifth percentile range.

Discussion

This study's main objective was to develop Wingate normative-reference standards, including percentile rankings and performance classifications, that are representative of the general young and healthy Canadian adult population. In this study, males produced higher absolute and

Table 2. Wingate Anaerobic Test PP, MP, and FI classifications for males

Classifications	PP (W)	PP (W · kg^{-1})	MP (W)	MP (W · kg^{-1})	FI (%)
Elite	>1,510	>16.16	>1,014	>12.94	<33.16
Excellent	1,277–1,510	14.11–16.16	902–1,014	11.30–12.94	33.16–43.21
Above average	1,044–1,276	12.06–14.10	790–901	9.66–11.29	43.22–53.27
Average	811–1,043	10.01–12.05	678–789	8.02–9.65	53.28–63.33
Below average	578–810	7.96–10.00	566–677	6.38–8.01	63.34–73.39
Fair	345–577	5.91–7.95	453–565	4.74–6.37	73.40–83.46
Poor	<345	<5.91	<453	<4.74	>83.46

Classifications for absolute PP and MP (in W) were calculated by rounding to the closest whole number value, and classifications for relative PP and MP (in W · kg^{-1}) and FI (%) were calculated by rounding to the closest two decimal places. Good (low) FI performance makes sense only if the PP is good, too; otherwise, a good (low) FI with poor PP means that the participant did not exert maximal effort, and continued slow, resulting in small decrement of performance.

Table 3. Wingate Anaerobic Test PP, MP, and FI classifications for females

Classifications	PP (W)	PP (W · kg^{-1})	MP (W)	MP (W · kg^{-1})	FI (%)
Elite	>1,079	>17.62	>816	>11.48	<32.36
Excellent	909–1,079	15.41–17.62	714–816	10.12–11.48	32.36–41.63
Above average	739–908	13.20–15.40	612–713	8.76–10.11	41.64–50.91
Average	569–738	10.99–13.19	510–611	7.40–8.75	50.92–60.19
Below average	399–568	8.78–10.98	408–509	6.04–7.39	60.20–69.47
Fair	229–398	6.57–8.77	306–407	4.68–6.03	69.48–78.76
Poor	<229	<6.57	<306	<4.68	>78.76

Classifications for absolute PP and MP (in W) were calculated by rounding to the closest whole number value, and classifications for relative PP and MP (in W · kg^{-1}) and FI (%) were calculated by rounding to the closest two decimal places. Good (low) FI performance makes sense only if the PP is good, too; otherwise, a good (low) FI with poor PP means that the participant did not exert maximal effort, and continued slow, resulting in small decrement of performance.

Table 4. Wingate Anaerobic Test PP, MP, and FI percentile rankings for males

Percentiles	PP (W)	PP (W · kg^{-1})	MP (W)	MP (W · kg^{-1})	FI (%)
5	620	8.61	449	6.41	42.01
10	672	9.26	490	6.81	45.73
15	733	9.65	527	7.01	47.34
20	768	10.01	547	7.33	49.20
25	799	10.35	579	7.49	50.94
30	839	10.67	602	7.64	52.67
35	858	10.89	616	7.78	54.05
40	879	11.21	632	7.98	55.56
45	907	11.45	647	8.11	57.07
50	924	11.66	659	8.21	58.05
55	953	11.95	671	8.38	59.71
60	981	12.16	689	8.52	60.88
65	1,015	12.35	702	8.66	61.70
70	1,050	12.62	715	8.77	62.92
75	1,078	12.84	735	8.92	64.46
80	1,108	13.15	752	9.00	65.82
85	1,149	13.47	777	9.11	67.39
90	1,208	14.05	822	9.30	70.27
95	1,269	14.93	870	9.49	73.39

Percentile rankings were calculated by rounding to the closest two decimal places. Classification in a higher percentile (e.g., 95%) for PP (W and W · kg^{-1}) and MP (W and W · kg^{-1}) is advantageous, whereas classification in a lower percentile (e.g., 5%) for FI is advantageous, as this means that the participant fatigued less during the course of the 30-second bout.

Table 5. Wingate Anaerobic Test PP, MP, and FI percentile rankings for females

Percentiles	PP (W)	PP (W · kg^{-1})	MP (W)	MP (W · kg^{-1})	FI (%)
5	369	6.58	282	4.69	40.86
10	419	6.93	310	5.12	43.53
15	447	7.24	330	5.36	46.13
20	470	7.53	341	5.50	48.11
25	489	7.77	352	5.66	49.98
30	500	7.99	365	5.85	51.14
35	514	8.23	374	5.99	52.19
40	526	8.47	381	6.14	53.47
45	546	8.69	391	6.32	54.48
50	561	8.95	404	6.40	55.78
55	580	9.11	418	6.51	56.62
60	597	9.27	429	6.67	57.82
65	615	9.47	442	6.78	58.77
70	639	9.72	455	6.90	60.33
75	658	9.96	468	7.06	61.79
80	683	10.37	488	7.26	62.62
85	713	10.84	507	7.51	64.06
90	760	11.17	539	7.81	66.02
95	846	11.98	579	8.24	69.08

Percentile rankings were calculated by rounding to the closest two decimal places. Classification in a higher percentile (e.g., 95%) for PP (W and W · kg^{-1}) and MP (W and W · kg^{-1}) is advantageous, whereas classification in a lower percentile (e.g., 5%) for FI is advantageous, as this means that the participant fatigued less during the course of the 30-second bout.

relative PP and MP values than females, whereas female participants had lower FI scores than male participants. These findings support common absolute and relative PP and MP [5, 28, 32, 36, 40] and FI [28, 32, 36, 40] patterns reported in the literature.

This study's overall population had higher PP (744 ± 252 W) and FI (56.58 ± 9.52%) values than those reported for the population studied by Ramírez-Vélez et al. [36] (PP: 527 ± 132 W, FI: 29.00 ± 15.70%). The PP and FI difference between studies of 217.03 W and 27.58%, respectively, suggests that the Canadian population demonstrated greater power output and likely, as a result, greater fatigue throughout the course of the 30-second bout. This pattern of higher absolute PP and FI values for the present Canadian population relative to the population studied by Ramírez-Vélez et al. [36] was also noted upon the separate examination of male and female populations.

To allow for comparison, Table 6 highlights the mean PP (W and W · kg^{-1}), MP (W and W · kg^{-1}), and FI values of male participants from this study and other studies that reported male Wingate data. PP values obtained for the average Canadian male adult population (939.17 ± 207.57 W) were higher than the values obtained for collegiate soccer players in Miller et al.'s [30] study (802.70 ± 155.60 W). This may be attributed to the off-season timing of the administration of Wingate testing among the high-level athletes studied by Miller et al. [30]. It may also result from the fact that the sport of soccer requires skills that are not solely focused on power output [30]. Additionally, this study's male participants also had higher PP and MP values relative to those reported for the physically active males studied by Maud and Schultz [28] (PP: 700 ± 95 W and 9.18 ± 1.43 W · kg^{-1}, MP: 563 ± 67 W and 7.28 ± 0.88 W · kg^{-1}). Conversely, the Canadian males tested in this study scored lower for both absolute PP (939 ± 208 W) and MP (657 ± 125 W) relative to the Division IA collegiate male football and track and field athletes (power focused sports) in Coppin et al.'s [11] study (PP: 1,084 ± 137 W, MP: 777 ± 81 W) (note: the resistance in Coppin et al.'s [11] study was set at 8.5% of participants' BMs). Similarly, the present study had lower values for PP (939 ± 208 W and 11.64 ± 1.95 W · kg^{-1}) and MP (657 ± 125 W and 8.13 ± 1.07 W · kg^{-1}) in comparison to the intercollegiate athletes from Zupan et al.'s [40] study (PP: 951 ± 141 W and 11.65 ± 1.39 W · kg^{-1}, MP: 686 ± 91 W and 8.47 ± 0.88 W · kg^{-1}) and the regularly physically active university-aged participants studied by Nikolaidis [32] (note: the resistance was set at 8.5% of participants' BM in kg) (PP: 1,046 ± 130 W and 13.52 ± 1.00 W · kg^{-1}, MP: 830 ± 98 W, 10.74 ± 0.71 W · kg^{-1}). However, Basist [5] reported PP, MP, and FI values (925 ± 165 W, 686 ± 131 W, and 49.00 ± 8.90%, respectively) for male participants that were close in range to those of the present study's male cohort (PP, MP, and FI values of 939 ± 208 W, 657 ± 125 W, and 57.34 ± 9.99%, respectively). Despite the present study having higher male PP (W) values, the participants in Basist's [5] study demonstrated higher MP (W) values and a lower FI. Given that the male participants in Basist's [5] study were exercise-trained, this may be a likely explanation for why they were able to generate greater MP (W), while not fatiguing as easily in comparison to this study's male participants.

Table 7 reports female mean PP (W and W · kg^{-1}), MP (W and W · kg^{-1}), and FI data from this study, as well as various other studies that analyzed female participants. This study's mean PP and MP for female participants (582 ± 151 W and 417 ± 97 W, respectively) was higher than the PP (455 ± 81 W) and MP (381 ± 56 W) values reported by Maud and Schultz [28], thus following a similar pattern as the male comparison. Additionally, the present study's PP and MP values were lower than the PP (640 ± 76 W) and MP (516 ± 53 W) data reported in the study conducted by Nikolaidis [32], which included participants who were accustomed to physical activity and

Table 6. Comparison of reported male PP, MP, and FI values

Study	PP (W)	PP (W · kg^{-1})	MP (W)	MP (W · kg^{-1})	FI (%)
Present study	939 ± 208	11.64 ± 1.95	657 ± 125	8.13 ± 1.07	57.34 ± 9.99
Basist	925 ± 165	10.90 ± 1.30	686 ± 131	8.10 ± 1.10	49.00 ± 8.90
Coppin et al.	1,084 ± 137	12.90 ± 1.50	777 ± 81	9.30 ± 0.90	49.00 ± 8.40
Miller et al.	803 ± 156	10.90 ± 1.20	651 ± 102	8.90 ± 0.60	35.90 ± 8.40
Maud and Schultz	700 ± 95	9.18 ± 1.43	563 ± 67	7.28 ± 0.88	37.67 ± 9.89
Nikolaidis	1,046 ± 130	13.52 ± 1.00	830 ± 98	10.74 ± 0.71	39.80 ± 6.59
Ramírez-Vélez et al.	567 ± 124	7.70 ± 2.40	N/A	N/A	29.50 ± 15.80
Zupan et al.	951 ± 141	11.65 ± 1.39	686 ± 91	8.47 ± 0.88	47.00 ± 7.60

PP – peak power; MP – mean power; FI – fatigue index; W – watts; W · kg^{-1} – watts per kilogram; N/A – not available. Basist, Coppin et al., and Nikolaidis used a resistance of 8.5% of participants' BMs in kg, as compared to the 7.5% used by all other studies in Table 6.

Table 7. Comparison of Reported Female PP, MP, and FI Values

Study	PP (W)	PP (W · kg^{-1})	MP (W)	MP (W · kg^{-1})	FI (%)
Present study	582 ± 151	9.02 ± 1.82	417 ± 97	6.45 ± 1.15	55.53 ± 8.98
Basist	596 ± 119	8.50 ± 1.20	441 ± 89	6.30 ± 1.00	49.00 ± 10.90
Baker et al.	673 ± 101	10.97 ± 0.95	456 ± 66	7.47 ± 0.73	53.23 ± 6.44
Bradley and Ball	576 ± 81	9.60 ± 0.90	430 ± 58	7.2 ± 0.60	44.30 ± 6.90
Maud and Schultz	455 ± 81	7.61 ± 1.24	381 ± 56	6.35 ± 0.73	35.05 ± 8.32
Nikolaidis	640 ± 76	10.56 ± 0.76	516 ± 53	8.52 ± 0.54	36.80 ± 6.93
Ramírez-Vélez et al.	462 ± 118	7.60 ± 2.20	N/A	N/A	28.10 ± 15.70
Zupan et al.	598 ± 88	9.59 ± 0.99	445 ± 64	7.16 ± 0.70	42.00 ± 7.90

PP – peak power; MP – mean power; FI – fatigue index; W – watts; W · kg^{-1} – watts per kilogram; N/A – not available. Baker et al. and Nikolaidis used a resistance of 8.5% of participants' BMs in kg, as compared to the 7.5% used by all other studies in Table 7.

engaged in sport regularly. Analysis of mean female PP (W) and MP (W and W · kg^{-1}) revealed values of 582 ± 151 W, 417 ± 97 W, and 6.45 ± 1.15 W · kg^{-1}, respectively. As expected, these values were lower than those reported for the highly-trained females tested by Zupan et al. [40] (PP: 598 ± 88 W, MP: 445 ± 64 W and 7.16 ± 0.70 W · kg^{-1}) and Baker et al. [2] (PP: 673 ± 101 W, MP: 456 ± 66W and 7.47 ± 0.73 W · kg^{-1}) (note: Baker et al. [2] used a resistance of 8.5% of participants' BMs in kg). Similar PP and MP values were observed when comparing results from Basist's [5] study (PP: 596 ± 119 W, MP: 441 ± 89 W) and data from the athlete (softball and field-hockey) and non-athlete participants studied by Bradley and Ball [6] (PP: 576 ± 81 W, MP: 430 ± 58 W) to the present study's values (PP: 582 ± 151 W, MP: 417 ± 97 W). Additionally, Basist [5] reported a FI score of 49.00 ± 10.90% among female participants, while the present study's FI value was 55.53 ± 8.98%. Since female participants in Basist's [5] study engaged in regular physical activity, this can be attributed to the higher PP (W) and MP (W), as well as the lower FI values compared to the present study (where not all participants were exercise-trained).

The aforementioned comparisons highlight the significance of this study and support its role in filling a gap that currently exists in the literature. There are several differences between this study's PP (W and W · kg^{-1}), MP (W and W · kg^{-1}), and FI values in comparison to the data reported in other studies that have focused on specific athletic [2, 11, 30, 40] or national [32, 36] populations, or that have evaluated small sample sizes [6, 28]. These limitations make it difficult to generalize the results of the aforementioned studies to a broader population composed of individuals with varying athletic abilities, much like this study's Canadian young adult population. In effect, to allow for practical applications, such as accurate comparison and analysis of PP (W and W · kg^{-1}), MP (W and W · kg^{-1}), and FI following Wingate testing, the development of normative-reference standards for healthy, young Canadian adults has been needed.

While many studies in the literature have established male and female percentile classifications based on collected Wingate data [2, 5, 27, 36], very few have constructed categorical classifications [40]. Participants' PP and MP (W and W · kg^{-1}) and FI (%) in Coppin et al.'s [11] study were classified using 'high', 'medium', and 'low' distinctions, preventing a direct comparison to the present study. However, Zupan et al. [40] constructed a comparable classification system for PP and MP (W and W · kg^{-1}) using categories, thus allowing for comparison. Rankings based on the sampled Canadian population's data designated the 'average' classification for male relative PP and MP values of 10.01–12.05 W · kg^{-1} and 8.02–9.65 W · kg^{-1}, respectively. These values are very close in range to the 'average' male classification for relative PP (11.65–12.34 W · kg^{-1}) and MP (8.02–8.90 W · kg^{-1}) reported by Zupan et al. [40]. The female data displayed similar patterns for the 'average' classification (PP: 10.99–13.19 W · kg^{-1}, MP: 7.40–8.75 W · kg^{-1}) compared to Zupan et al. [40] (PP: 9.10–10.07 W · kg^{-1}, MP: 6.81–7.50 W · kg^{-1}). In the present study, males who scored >1,510 W (or >16.16 W · kg^{-1}) for PP, >1014 W (or >12.94 W · kg^{-1}) for MP, and <33.16% for FI would be classified as 'elite', while females would require a PP value of >1,079 W (or >17.62 W · kg^{-1}), a MP value of >816 W (or >11.48 W · kg^{-1}), and a FI value of <32.36% for 'elite' classification. Zupan et al.'s [40] 'elite' classification for male (PP of >1,163 W and >13.74 W · kg^{-1}, MP of >823 W and >9.79 W · kg^{-1}) and female (PP of >730 W and >11.07 W · kg^{-1}, MP of >541 W and >8.22 W · kg^{-1}) participants was lower in comparison to this study. The lower ranges for female classifications compared to male classifications seen among the Canadian young adult population is consistent

with the current literature [40]. Specifically, males tend to score higher on all Wingate variables compared to females [5, 28, 32, 36, 40], a finding that may be attributed to sex differences in biological makeup and capacity of the human systems [40].

Percentile rankings created based on the present Canadian adult population designated the 50th percentile for PP and MP to be 924 W and 659 W, respectively, for males, and 561 W and 404 W, respectively, for females. A pattern of higher values for males was noted for all percentile rankings. The present study's female population showed a pattern of lower values across all percentile rankings in comparison to Baker et al.'s [2] study, which included highly-trained female athletes, and Basist's [5] study, which focused on active and healthy adults (similar age range to this study). The higher percentile rankings among Baker et al.'s [2] participants may be attributed to a greater level of fitness and athletic ability in comparison to the general Canadian population, but this cannot be confirmed, as this type of demographic data was not collected. Higher values in Basist's [5] study could also be attributed to the exercise-trained nature of the participants, as adaptations to exercise can be reflected in a higher anaerobic power output. The PP percentile rankings developed for the Colombian population aged 20 to 25 years studied by Ramírez-Vélez et al. [36] demonstrated lower values (males: 666 W, females: 512 W) in comparison to the present population (males: 924 W, females: 560 W), which included a similar age range.

Future research should consider focusing on the development of normative values and percentile rankings for the general adult population from different countries, to see how closely they are linked to the current Canadian results. In order to collect such a large sample size, thus allowing for an in depth understanding and analysis of the data, the present study specifically focused on young adults aged 20 to 29 years. However, future research should expand to assess and develop Wingate normative-reference values for specific populations (e.g., separating athletes and non-athletes, individuals of certain fitness levels or training statuses, BMs, and ages, males and females, etc.) and older age groups (e.g., young [i.e., 25-to-45 years] and middle [i.e., 45-to-65 years] adult populations) to determine if similar trends exist. These values may be especially relevant for adult populations 45+ years of age who participate in recreational activities or sport, as the current demographic shift toward an older population may lead to further emphasis on the importance of physical activity, consequently, decreasing the economic strain on the healthcare system due to morbidities. Furthermore, comparison of similar Wingate protocols and different resistances (e.g., 7.5% compared to 8.5% of BM in kg) would also be valuable.

Conclusion

This study's main focus was to develop Wingate normative-reference standards, percentile rankings, and performance classifications for a large cohort of Canadian university students. The Wingate Anaerobic Test provides valuable insight into an individual's anaerobic capabilities and consequently, their performance in athletic and fitness endeavors. Normative tables are a useful tool for baseline fitness assessment and to monitor training improvements, and they can potentially serve as health indicators based on participants' percentile or classification rankings. For example, participants ranking in the lower percentiles (i.e., below the 50th percentile) or classifications (i.e., 'below average', 'fair', or 'poor') may need improvement in fitness and overall functionality. Lastly, it is also important to note that the development of normative values for varying countries and age cohorts would supplement the existing literature and could lead to the development of global norms.

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