# WINGATE MUSCULAR POWER TEST REFERENCE VALUES FOR ACTIVE HEALTHY ADULTS AGES 19-29: NORMATIVE DATA AND DIFFERENCES BETWEEN SEX

By

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# ABSTRACT

# WINGATE MUSCULAR POWER TEST REFERENCE VALUES FOR ACTIVE HEALTHY ADULTS AGES 19-29: NORMATIVE DATA AND DIFFERENCES BETWEEN SEX

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The Wingate Muscular Power Test (WMPT) has existed for several decades and to this day is considered the gold standard for evaluating an individual's muscular power. However, the utility of this test is predicated on having accurate and relevant normative data with which to compare individual results. At present, the existing literature on this subject is either several decades old and/or inclusive of only specific subject groups (i.e. men only or sport-specific athletes). This study presents WMPT normative values for active healthy adults ages 19-29, separated by sex. The sample consisted of 330 active healthy volunteers (186 men and 144 women). Peak and mean power in absolute and relative value as well as fatigue index were all recorded. Three different relative powers were calculated based on body mass, lean body mass, and body mass to the two-thirds power. 19-29 age specific normative power and fatigue index values among healthy adults are defined. Peak and relative power results were higher for men than women, but not fatigue index. The norms for absolute power, relative power, and fatigue index produced from this study are considerably higher than previously developed norms. Normative reference value tables were generated and can be used by college-age active health adults and campus recreational club coaches to evaluate muscular power and fatigue index in their recreational athletes.

Key Words: healthy adults, reference values, physical conditioning, anaerobic power, anaerobic capacity

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# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# INTRODUCTION

Having a reliable method to test an individual’s maximum anaerobic power is essential for assessing fitness level, changes in muscular power, and an individual's capacity to perform in sports or exercises that require powerful bursts of activity (Brown and Weir, 2001). The Wingate Muscular Power Test (WMPT) was developed in the 1970s by the Wingate Institute in Israel (Ayalon et al., 1974). In addition to peak power (PP), the WMPT can also be utilized to measure an individual’s relative power (RP) based on their body mass (BM), mean power (MP), and their rate of muscular fatigue (known as fatigue index, FI). Since its inception, it has proven to be a reliable as well as valid assessment and thus is regarded as the gold standard for measuring anaerobic power (Dotan & Inbar,1977; Harvey et al., 2017). The procedure is safe, non-invasive, requires minimal training to administer, and the equipment utilized (cycle and arm ergometer) is already commonly found in most exercise science facilities (Brown and Weir, 2001).

Due to the relative nature of anaerobic power results, it’s critically important to have accurate normative data in order to compare an individual's results to that of an analogous population (Hoffman, 2006). A large portion of this exercise research is done at universities with the subjects of those studies often being students in attendance (NSF, 2017). Therefore, it stands to reason that having normative data from a robust sample of college-age men and women (both athletes and non-athletes) would provide a substantial aid to future research and analysis of collegiate athletic performance. Studies in the past have attempted to address this, but generally their sample sizes and/or population demographics are highly limited and therefore the applicability of the research findings is significantly reduced. One such study conducted by Zupan et al. (2009) utilized only intercollegiate (NCAA Division I) athletes. Another study by Baker et al. (2011) sampled only highly trained young women athletes. A third set of normative data research was provided by Coppin et al. (2012) from a sample of trained male college athletes. These studies provide normative data that can be useful within their narrow field of research but cannot be applied to a broader collegiate population. Two other factors that limit the applicability of past WMPT research are modest sample sizes (Table 1) and a lack of racial diversity (Ramírez-Vélez et al., 2016). This study seeks to address these limitations by providing WMPT normative data based on a robust sample size of healthy active college-age participants who are non-racially homogenous (Table 3).

Another potential issue with the current research data has to do with the procedures by which the data was collected. Certain testing conventions have been widely adopted, but no universal procedure exists yet (Brown & Weir, 2001). Some of the testing procedures in question relate to which calculation method to use when applying weighted resistance to record PP (Hermina, 1999; Vargas et al., 2015). Another consideration in the WMPT procedure that can vary between testing protocols is the method by which the weighted resistance is applied (Robergs et al., 2015). Other considerations such as cycle ergometer revolutions per minute (rpm) and the flywheel kinetic energy must be taken into account due to their effect on PP output (Bassett, 1989; Hermina, 1999).

Based on a review of the existing literature, the two primary areas of concern for WMPT normative data relate to the sample populations and the application of standardized testing procedures. With regards to the sample population, several studies have sought to fill this gap in the literature (Table 1), but oftentimes their sample sizes and/or population demographics prove to be highly specific and therefore limited in applicability. Additionally, normative data is only useful when compared to results produced from the same testing procedures. In order to generate normative data that could be utilized widely, but also maintain high standards of accuracy and reliability, this study analyzed and referenced other research procedures and followed the most efficacious testing guidelines currently available.

**Table 1**. Comparison of existing WMPT normative data

| Author | Resistance level | Subjects (Men/Women) | Type of participant | Age range of participant |
|---|---|---|---|---|
| Maud and Schultz | 7.5 | 112 / 74 | Physically active | College age (18-28) |
| Zupan et al. | 7.5 | 1,374 / 211 | College athletes | College age (18-25) |
| Coppin et al. | 8.5 | 77 Men | Power athletes | College age |
| Baker et al. | 8.5 | 107 Women | College athletes | College age (18-30) |
| Ramírez-Vélez et al. | 7.5 | 1,177 / 667 | Healthy adults | Adults (20-80) |

The purpose of this study was to collect, analyze, and share WMPT normative data that accurately reflects a broader collegiate population than has previously been published while additionally utilizing the most reliable and valid data collection methods. The subject population of this study to collect WMPT normative data includes both sexes, varying athletic abilities, diversity in age, and is non-racially homogenous.

# METHODS

## Experimental Approach to the Program

This study was conducted in the Human Performance Lab at Humboldt State University. The normative data collected was obtained from a sample of 330 subjects (144 women; 186 men) while performing a standardized WMPT utilizing a resistance based on a percent of the subject's BM. The standards of 7.5% of BM for women and 8.5% for men was determined based on the established experimental procedures (Brown et al., 2001). Participants were recruited and tested from December 2015 until May 2019. Measurements of absolute and relative power (peak/mean), and FI (%) were all collected. Additionally, three relative power (RP) categories were utilized. The first RP measurement was simply based on the power to mass ratio (watt·kg$^{-1}$). The second RP measurement was calculated utilizing the subject's lean body mass (LBM) (watt·kgLBM$^{-1}$). The third RP measurement was based on the classic formula (watt·kg$^{-2/3}$) which is less biased against heavier subjects (Haff and Triplett, 2016).

## Subjects

A total of 330 active healthy volunteers (186 men; 136 women) between 19 and 29 years of age were recruited for participation in this research. Many subjects participated in club or recreational sports (64.7% of men and 52.9% of women), but not college varsity sports such as football, soccer, track and field, etc. All subjects regularly participated in moderate or strenuous exercise for a minimum of 3 days per week for a period of at least

4 weeks prior to participation. Moderate physical activity is defined as any form of activity that takes 3.0-5.9 METs to complete, such as brisk walking, shooting around in basketball, dancing, golf, tennis, and volleyball. Vigorous activity is defined as any activity that requires 6 or more METs to complete, such as jogging and running, bicycling, soccer, swimming, or performing heavy lifting (ACSM, 2013). Subjects were screened for cardiovascular and musculoskeletal disease using a medical history questionnaire, an activity questionnaire, and the Physical Activity Readiness Questionnaire (PAR-Q). Subjects were asked about and subsequently were excluded from the study if they were found to have two or more cardiovascular risk factors as outlined by the American College of Sports Medicine (2013). Subjects were also asked about their use of ergogenic supplements (e.g. pharmacologic aids and/or dietary supplements) that could affect their exercise performance and were excluded from the study if they regularly used them. After the initial screening, body density was determined using the sum of 3 skin fold sites and the Jackson and Pollock equations; ethnic and sex specific equations were used to calculate the percentage of body fat from body density. This study was approved by the Humboldt State University Institutional Review Board, and subjects were informed of the risks and benefits of the investigation prior to signing an informed consent form to participate in the study.

## Procedures

Each subject was instructed to complete a general warm-up session following self-paced jogging for five minutes on the treadmill and dynamic stretching focused on large muscle groups in the lower limbs such as quadriceps, hamstring, and gluteal muscles (static stretching, 10 seconds per stretch, 4-5 repetitions per exercise, and total stretching time was less than 60 seconds per exercise). Additionally, subjects performed a familiarized submaximal cycling session with 1kg resistance at 50 rpm, including a pair of five second maximal sprints on the Monark cycling ergometer (Model 894Ea, Monark, Sweden). After completing the warm-up session, subjects rested for five minutes before the actual data collection commenced. The resistance was set at 7.5% of body mass (kg) for women and 8.5% of body mass for men. Before performing the WMPT, bike fit (i.e., handlebar, saddle height) was checked and the appropriate resistance was set up on the equipped basket of the cycle ergometer based on subjects' sex and body mass in kilograms. All subjects were verbally encouraged to continue to pedal as fast as they could for 30 seconds and remain seated on the saddle throughout the test. At the beginning of the WMPT, the weighted basket automatically dropped when subjects' cadence reached 110rpm. After data collection began, the test ran for 30 seconds while being monitored by research technicians. Verbal encouragement was provided by the research team throughout the duration of the test. Pedal revolutions were recorded for each 5-second segment using the Monark Wingate Software (Monark Anaerobic Test Software Version 3.2.1.0) following four main variables: absolute and relative PP, absolute and relative MP, and FI. After data collection concluded, subjects were instructed to remain seated and pedal at a lower resistance for five minutes as a cooldown phase.

## Statistical Analyses

The normal distribution of the data was verified using a Kolmogorov-Smirnov test. Anthropometric data, absolute peak and mean power (Watts), relative peak and mean power (watt·kg$^{-1}$, watt·kgLBM$^{-1}$, and watt·kg$^{-2/3}$), and fatigue index (% decrement of power) were reported as mean ± standard deviation (*SD*). All data were analyzed separately to provide percentile values for men and women. The descriptive statistics were calculated in mean, standard deviation, minimum, and maximum. A t-test for independent means was used to verify the differences between men and women. We used GraphPad Prism 9.0 (GraphPad Software, Inc., San Diego, CA) and Microsoft Office Excel for Windows 2016, and significance for all the statistical tests were set at $p < 0.01$.

# RESULTS

Table 2 shows the aggregated anthropometric data of all research participants. Also listed are the comparative values for absolute power, relative power, and fatigue index means for men and women in this study. There was no significant difference between the mean age of men and women who participated ($p = 0.035$, Table 2). Additionally, the mean for fatigue index did not show a statistically significant difference ($p = 0.49$, Table 2) between men and women. However, a significant difference was identified between men and women for all other anthropometric data and power measurements (Table 2).

Table 4 shows the sex based normative value for PP (in watts, in watt·kg$^{-1}$, in watt·kgLBM$^{-1}$, and in watt·kg$^{-2/3}$) of the WMPT in healthy adults, classified according to sex and expressed in percentiles from 1 to 99. Table 5 shows the sex based normative value for MP (in watts, in watt·kg$^{-1}$, in watt·kgLBM$^{-1}$, and in watt·kg$^{-2/3}$) of the WMPT in the healthy adults, classified according to sex and expressed in percentiles from 1 to 99. Table 6 shows percentile normative value for fatigue index of the WMPT in the healthy adults, classified according to sex and expressed in percentiles from 1 to 99.

Figures 1 shows relative peak and mean powers of the WMPT in the healthy adults, classified according to sex and expressed in percentiles from 5 to 95. Figure 2 shows power and cadence (rpm) of the WMPT for 30 seconds in men and women. Figure 3 shows fatigue index (%) of the WMPT in the healthy adults, classified according to sex and expressed in percentiles from 5 to 95.

**Table 2**. Characteristics of the study sample by sex (mean ± *SD*).

| Characteristics | All ($n = 330$) | Men ($n = 186$ ) | Women ($n = 144$ ) | Difference and $p$ for sex |
|---|---|---|---|---|
| Age | 22.5 ± 2.4 | 22.7 ± 2.4 | 22.2 ± 2.2 | 97.6 %, $p = 0.035$ |
| Body mass (kg) | 79.4 ± 17.2 | 85.8 ± 16.4 | 71 ± 15 | 82.9%, $p < 0.01$ |
| Height (cm) | 172.9 ± 9.9 | 178.5 ± 7.4 | 165 ± 7 | 92.8%, $p < 0.01$ |
| Body mass index (kg/m$^2$) | 26.5 ± 4.9 | 25.4 ± 2.8 | 23.8 ± 3 | 95.9%, $p < 0.01$ |
| Body fat (%) | 18.8 ± 6.7 | 15.0 ± 5.5 | 23.7 ± 4.7 | 157.9%, $p < 0.01$ |
| Resistance load (kg) | 6.4 ± 1.6 | 7.3 ± 1.4 | 5.3 ± 1.1 | 73.0%, $p < 0.01$ |
| Peak power (watts) | 781.1±219.6 | 924.8 ± 165.4 | 595.5 ± 118.5 | 64.4%, $p < 0.01$ |
| Peak power (watt·kg$^{-1}$) | 9.8 ± 1.7 | 10.9 ± 1.3 | 8.5 ± 1.2 | 77.8%, $p < 0.01$ |
| Peak power (watt·kgLBM$^{-1}$) | 12.2 ± 2.0 | 13.1 ± 2.0 | 11.1 ± 1.4 | 84.5%, $p < 0.01$ |
| Peak power (watt·kg$^{-2/3}$) | 41.4 ± 8.0 | 46.9 ± 5.3 | 34.3 ± 4.6 | 73.1%, $p < 0.01$ |
| Mean power (watts) | 579.0 ± 167.5 | 686.1 ± 131.4 | 440.6 ± 89.4 | 64.3%, $p < 0.01$ |
| Mean power (watt·kg$^{-1}$) | 7.3 ± 1.4 | 8.1 ± 1.1 | 6.3 ± 1.0 | 78.0%, $p < 0.01$ |
| Mean power (watt·kgLBM$^{-1}$) | 9.1 ± 1.6 | 9.6 ± 1.6 | 8.2 ± 1.2 | 84.5%, $p < 0.01$ |
| Mean power (watt·kg$^{-2/3}$) | 30.7 ± 6.3 | 34.8 ± 4.5 | 25.4 ± 4.0 | 73.1%, $p < 0.01$ |
| Fatigue Index (%) | 49.0 ± 9.8 | 49.0 ± 8.9 | 49.0 ± 10.9 | 100.1%, $p = 0.49$ |

**Table 3**. Self-reported race identification of study sample

| Race | All | Men | Women |
|---|---|---|---|
| White | 45.5% | 43.9% | 47.2% |
| Hispanic or Latino | 37.3% | 34.8% | 40.3% |
| Black or African American | 7.3% | 9.1% | 4.9% |
| Asian | 3.0% | 3.2% | 2.8% |
| American Indian or Alaska Native | 1.2% | 1.1% | 1.4% |
| Unknown or no response | 5.8% | 8.0% | 3.5% |

**Table 4.** Percentile norms and descriptive statistics for peak power of the Wingate muscular power test

| Percentile Rank | Male watts | Female watts | Male watt·kg$^{-1}$ | Female watt·kg$^{-1}$ | Male watt·kgLBM$^{-1}$ | Female watt·kgLBM$^{-1}$ | Male watt·kg$^{-2/3}$ | Female watt·kg$^{-2/3}$ |
|---|---|---|---|---|---|---|---|---|
| 99 | 1323.5 | 871.7 | 13.6 | 10.8 | 18.9 | 14.1 | 57.6 | 43.3 |
| 95 | 1215.2 | 797.7 | 12.9 | 10.0 | 16.4 | 13.3 | 55.8 | 41.0 |
| 90 | 1149.4 | 740.0 | 12.6 | 9.8 | 15.4 | 12.8 | 54.2 | 40.2 |
| 85 | 1095.0 | 719.1 | 12.3 | 9.6 | 15.0 | 12.7 | 53.4 | 39.2 |
| 80 | 1071.0 | 693.4 | 11.9 | 9.4 | 14.5 | 12.1 | 51.6 | 37.9 |
| 75 | 1036.0 | 682.5 | 11.7 | 9.3 | 14.2 | 12.0 | 50.5 | 37.3 |
| 70 | 997.6 | 666.7 | 11.6 | 9.0 | 13.9 | 11.7 | 49.2 | 36.6 |
| 65 | 971.2 | 639.6 | 11.4 | 8.9 | 13.7 | 11.6 | 48.5 | 36.1 |
| 60 | 953.6 | 609.9 | 11.2 | 8.8 | 13.5 | 11.5 | 47.8 | 35.1 |
| 55 | 924.8 | 592.6 | 11.0 | 8.7 | 13.2 | 11.3 | 47.3 | 34.9 |
| 50 | 901.5 | 579.9 | 10.8 | 8.6 | 13.0 | 11.1 | 46.9 | 34.3 |
| 45 | 888.3 | 568.0 | 10.7 | 8.4 | 12.8 | 10.9 | 46.0 | 33.9 |
| 40 | 873.6 | 556.0 | 10.5 | 8.3 | 12.7 | 10.7 | 45.4 | 33.5 |
| 35 | 851.1 | 546.8 | 10.3 | 8.2 | 12.4 | 10.6 | 44.6 | 32.8 |
| 30 | 825.4 | 532.0 | 10.2 | 8.0 | 12.0 | 10.5 | 43.9 | 32.5 |
| 25 | 802.3 | 521.9 | 10.1 | 7.8 | 11.8 | 10.4 | 43.5 | 31.7 |
| 20 | 793.5 | 503.0 | 9.7 | 7.6 | 11.6 | 10.0 | 42.4 | 30.8 |
| 15 | 772.1 | 488.2 | 9.5 | 7.1 | 11.3 | 9.7 | 41.6 | 29.4 |
| 10 | 739.5 | 453.1 | 9.3 | 6.9 | 10.8 | 9.4 | 40.9 | 28.2 |
| 5 | 702.3 | 410.4 | 9.0 | 6.4 | 10.2 | 8.7 | 37.3 | 26.9 |
| 1 | 563.7 | 358.7 | 8.1 | 5.7 | 8.5 | 7.6 | 34.6 | 24.0 |
| Maximum | 1448.4 | 939.8 | 14.1 | 11.8 | 20.8 | 14.7 | 60.2 | 45.9 |
| Minimum | 552.0 | 227.1 | 6.9 | 4.0 | 7.9 | 5.1 | 33.3 | 15.1 |

Note, *n* = Men 186, Women 144

**Table 5**. Percentile norms and descriptive statistics for mean power of the Wingate muscular power test

| Percentile Rank | Male watts | Female watts | Male watt·kg$^{-1}$ | Female watt·kg$^{-1}$ | Male watt·kgLBM$^{-1}$ | Female watt·kgLBM$^{-1}$ | Male watt·kg$^{-2/3}$ | Female watt·kg$^{-2/3}$ |
|---|---|---|---|---|---|---|---|---|
| 99 | 1042.3 | 626.7 | 10.1 | 8.2 | 14.3 | 10.6 | 45.0 | 32.7 |
| 95 | 929.4 | 569.6 | 9.8 | 7.7 | 12.5 | 10.1 | 41.6 | 31.1 |
| 90 | 846.2 | 550.1 | 9.4 | 7.6 | 11.6 | 9.7 | 40.3 | 30.0 |
| 85 | 809.2 | 534.3 | 9.0 | 7.4 | 11.2 | 9.5 | 39.4 | 29.5 |
| 80 | 772.9 | 519.9 | 8.9 | 7.3 | 10.8 | 9.3 | 38.1 | 28.9 |
| 75 | 756.3 | 503.8 | 8.7 | 7.1 | 10.6 | 9.0 | 37.6 | 28.5 |
| 70 | 744.1 | 493.2 | 8.6 | 6.9 | 10.4 | 8.9 | 37.1 | 28.0 |
| 65 | 730.2 | 476.6 | 8.4 | 6.9 | 10.1 | 8.7 | 36.5 | 27.5 |
| 60 | 714.1 | 467.2 | 8.3 | 6.6 | 10.0 | 8.6 | 36.0 | 27.1 |
| 55 | 702.9 | 456.9 | 8.2 | 6.5 | 9.9 | 8.5 | 35.7 | 26.4 |
| 50 | 686.7 | 447.6 | 8.1 | 6.4 | 9.6 | 8.3 | 34.9 | 26.1 |
| 45 | 662.8 | 439.4 | 8.0 | 6.2 | 9.4 | 8.2 | 34.2 | 25.3 |
| 40 | 649.7 | 426.0 | 7.8 | 6.1 | 9.3 | 8.1 | 33.4 | 24.5 |
| 35 | 625.4 | 409.4 | 7.7 | 5.9 | 9.2 | 8.0 | 32.9 | 23.8 |
| 30 | 610.6 | 393.2 | 7.5 | 5.7 | 9.0 | 7.8 | 32.4 | 23.3 |
| 25 | 590.8 | 380.1 | 7.4 | 5.5 | 8.9 | 7.6 | 31.8 | 22.7 |
| 20 | 573.3 | 366.3 | 7.3 | 5.3 | 8.4 | 7.2 | 31.2 | 22.2 |
| 15 | 550.9 | 347.6 | 7.0 | 5.1 | 8.1 | 7.0 | 30.7 | 21.3 |
| 10 | 531.9 | 330.6 | 6.7 | 4.9 | 7.8 | 6.6 | 29.1 | 20.1 |
| 5 | 506.2 | 275.1 | 6.3 | 4.4 | 7.4 | 5.9 | 27.2 | 18.5 |
| 1 | 413.9 | 245.6 | 5.6 | 3.9 | 6.3 | 5.2 | 25.2 | 15.6 |
| Maximum | 1110.4 | 636.1 | 12.5 | 8.3 | 15.2 | 10.8 | 54.9 | 34.5 |
| Minimum | 392.8 | 198.1 | 5.3 | 3.5 | 5.6 | 4.5 | 24.9 | 13.1 |

Note, *n* = Men 186, Women 144

**Table 6**. Percentile norms and descriptive statistics for fatigue index of the Wingate muscular power test

| Percentile Rank | Male Fatigue Index | Female Fatigue Index |
|---|---|---|
| 99 | 68.7% | 69.4% |
| 95 | 60.9% | 63.3% |
| 90 | 59.5% | 61.5% |
| 85 | 57.7% | 59.0% |
| 80 | 56.3% | 57.0% |
| 75 | 54.9% | 55.8% |
| 70 | 53.8% | 54.1% |
| 65 | 52.5% | 53.0% |
| 60 | 51.7% | 52.4% |
| 55 | 51.0% | 49.8% |
| 50 | 49.6% | 47.8% |
| 45 | 48.9% | 46.6% |
| 40 | 47.8% | 46.2% |
| 35 | 46.7% | 45.0% |
| 30 | 45.8% | 43.2% |
| 25 | 43.8% | 40.7% |
| 20 | 42.0% | 39.5% |
| 15 | 40.3% | 38.0% |
| 10 | 38.1% | 35.7% |
| 5 | 33.6% | 32.8% |
| 1 | 24.4% | 29.5% |
| Maximum | 74.1% | 72.0% |
| Minimum | 21.7% | 18.4% |

Note, *n* = Men 186, Women 144

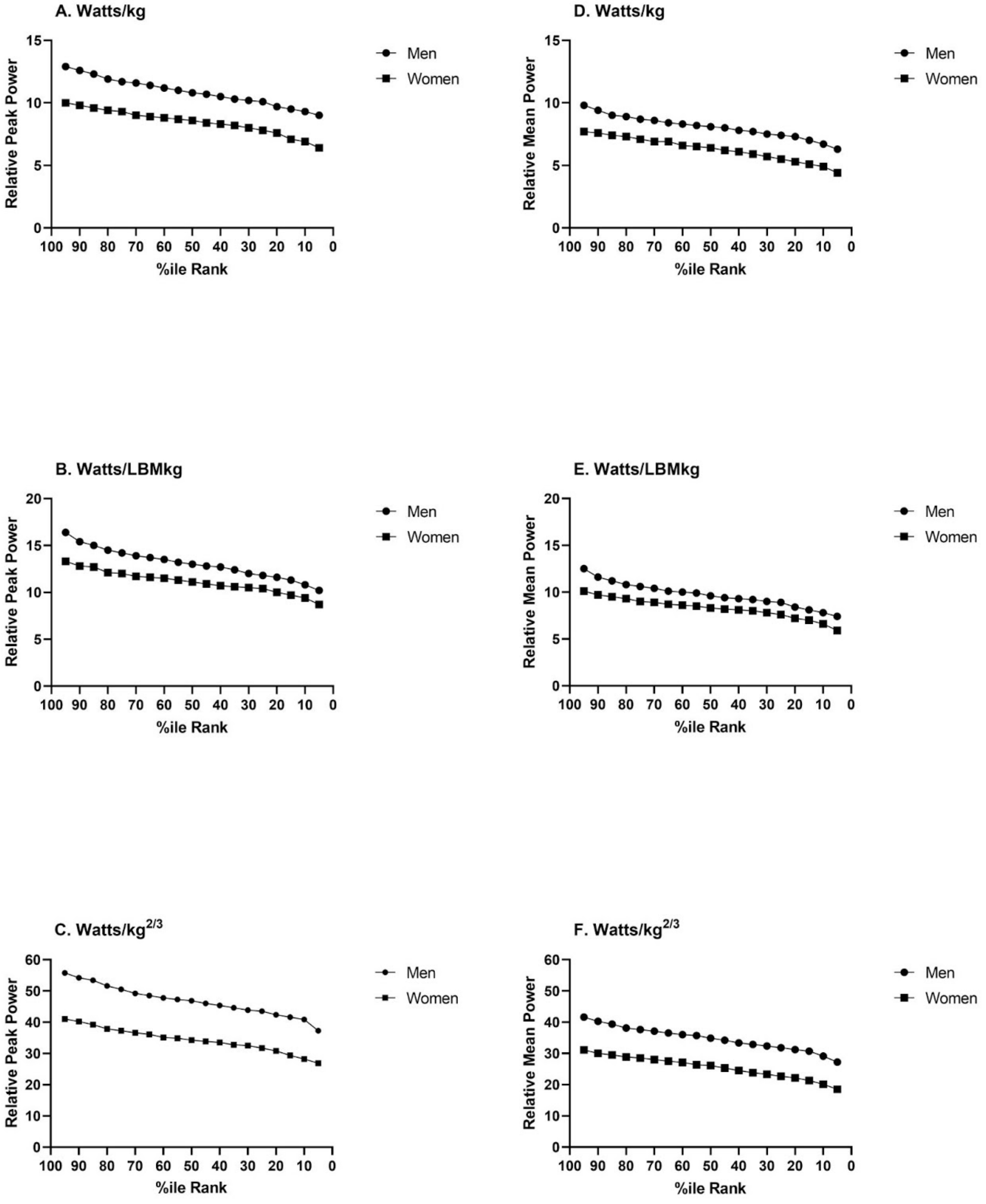

**Figure 1**. Relative peak and mean powers by percentile and sex

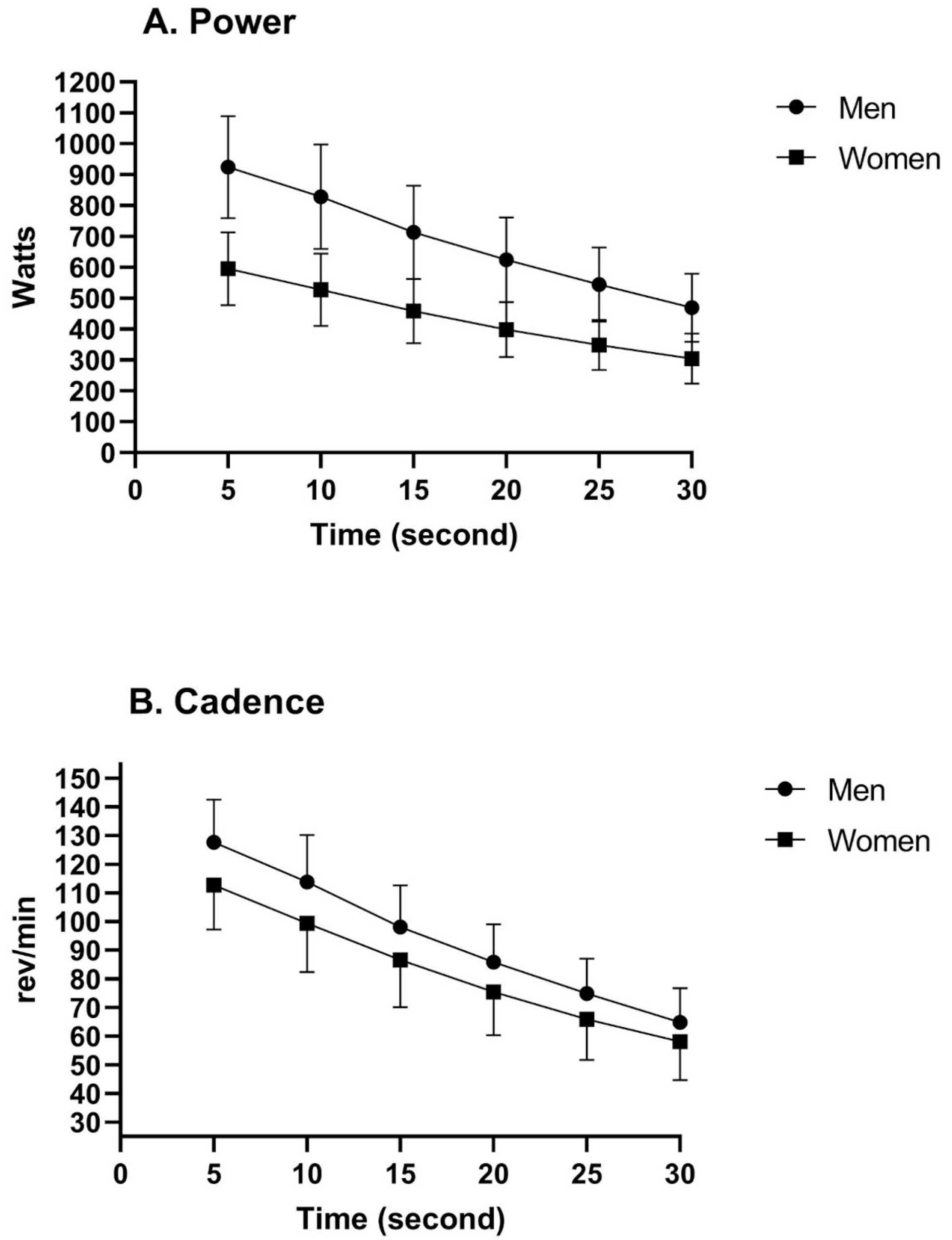

**Figure 2**. Power and cadence (rpm) for WMPT for 30 seconds in men and women

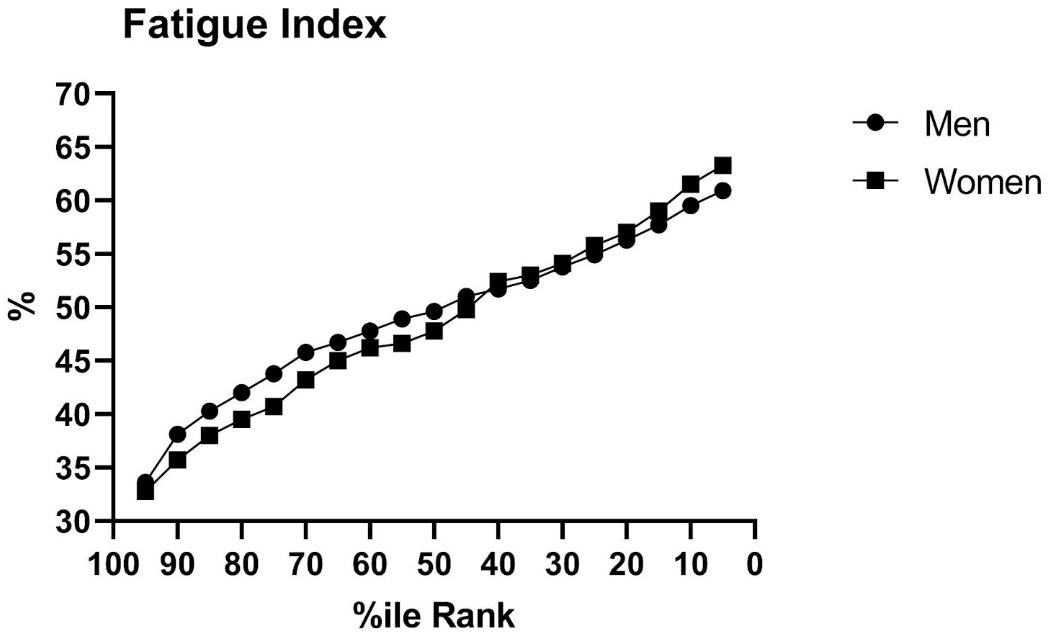

**Figure 3**. Fatigue index (%) by percentile and sex

# DISCUSSION

The WMPT is a commonly utilized method for collecting and evaluating anaerobic power and capacity performance. However, in order for these evaluations to be interpreted and valid, the normative data with which it is compared must reflect a robust and diverse sample population and utilize proper testing methods. In response to the lack of reference values for healthy general populations, the main objective of this study was to establish reference values for the WMPT among active healthy adults aged 19-29 years (Tables 4, 5, and 6).

Most fitness assessment and exercise physiology textbooks cite the WMPT norms by Maud and Shultz (1989), which is one of the only available reference values for the WMPT for the general population (Hoffman, 2006). However, those norms were developed using the old version of the Monark cycle ergometer without a computer, which makes the values not directly applicable to the current Monark cycle ergometer with a computer for anaerobic testing (Model 894Ea, Monark, Sweden). Moreover, these norms were recorded over thirty years ago and are not available at most academic laboratories or commercial gyms in the world nowadays.

Several steps were taken in this study to address and update known deficiencies in the current literature. The data for this research was collected from a representative sample of a racially diverse college population (Table 3). Additionally, the composition of men to women (56%/44%) who participated is far more balanced than some other widely used WMPT normative data which range from 64%/36% (Ramírez-Vélez et al., 2016) to 87%/13% (Zupan et al., 2009). These two factors alleviate the traditional bias inherently present in a substantial portion of research from past decades (Konkel, 2015). Furthermore, the sample size of 330 participants is nearly twice as large as one of the most widely used normative data sets (Maud and Schultz, 1989). This robust sample size provides sufficient statistical power to enable valid comparative assessments.

Our data confirms the common finding of higher peak, mean, and relative power data in men compared to women (Table 2). Lower-body muscular power output appears to be higher in men than women (Zupan et al., 2009). This difference between men's and women's values can also be due to significant differences in height, percent body fat, and fat free mass, as demonstrated by Maud and Schultz (1989). In a previous study, Maud and Schultz (1986) corrected for fat free mass and found no significant difference between male and female subjects in anaerobic power output relative to fat-free mass. However, in the present study, peak power for women (595.5 ± 118.5 watts) was 64.4% of the value observed in men (924.8 ± 165.4 watts) ($p < .01$), women's mass corrected peak power (8.5 ± 1.2 watts/kg$^{-1}$) was 77.8% of men (10.9 ± 1.3 watts/kg$^{-1}$) ($p < .01$), and women's LBM corrected peak power (11.1 ± 1.4 watt·kgLBM$^{-1}$) was 84.5% of men (13.1 ± 2.0 watt·kgLBM$^{-1}$) ($p < .01$). Our data shows sex differences in power output of WPMT diminished with the use of relative corrections (body mass and lean body mass) of the absolute value, but still there are significant difference between male and female subjects in relative power output. Interestingly, women's body mass to the two-thirds power (the classic formula) corrected peak power (34.3 ± 4.6 watts/kg$^{-1}$) was 73.1% (lowest, compared to 77.8% of BM and 84.5% of LBM) of men (46.9 ± 5.3 watt·kg$^{-2/3}$) ($p < .01$) because the classic formula has since been developed to favor heavier athletes over lighter athletes. Zupan et al. (2009) showed a large sex difference in which men averaged 11.65 relative peak power, whereas women averaged 9.59. That study and the present study used larger subject populations and thus have higher normalized power to generalize power by fat free mass than Maud and Shultz (1986). Therefore, although results from the WMPT have been mixed, men appear to have higher absolute and relative lower-body power output than women.

However, there was not a statistically significant difference ($p = 0.49$) between men and women with regards to the fatigue index (Table 2). This finding is consistent with previous WMPT normative data (Maud and Shultz, 1989). The power output data from this study differed dramatically from other previous WMPT normative data. The cause of this discrepancy can likely be attributed to differences in subject populations or methodology. In the study by Coppin et al., all subjects tested were college-age power athletes. This is in contrast to the active, but non-sport specific college-age subjects tested in this study. Although power athletes are an athletic group that would highly benefit from anaerobic power assessment, their training and physique would clearly increase their power output above an average or even active healthy adult, such as those utilized in this study. A similar contrast is seen when our results are compared to the normative power data of Zupan et al. The subjects of that study were all collegiate athletes which would likely skew the average power output higher than that of non-athletes. The normative data of Ramírez-Vélez et al. displayed lower values in power output than this study. However, this can likely be attributed to a broader age range and older average age in their study than in ours (38.1 ± 11.7 vs 22.5 ± 2.4 years old). This is supported by evidence from previous studies that have demonstrated the trend of decreased power output, especially explosive power, associated with individuals older than 40 (Metter et al., 1997). One final example of differing power output is seen in comparison to the data of Maud and Schultz (1989) which is one of the most widely cited studies for WMPT normative data. The peak power averages listed are significantly lower than the averages reported in this study (31% lower for women and 32% for men). Unlike the discrepancies previously discussed, this difference is not likely caused by a difference in test subjects since both studies enlisted college-aged adults of similar age and activity level. The subjects of their study included varsity athletes or physical education students, but all were considered physically active. Therefore, the considerably lower results for power output in their study are most likely due to utilization of research equipment that would be considered antiquated by today’s standards as well as less efficacious experimental methodology. All these differences in mean power output underscore the critical importance of utilizing normative data that was established with subjects who closely relate to the individual being compared. These characteristics include age, activity level, and sex. Additionally, the equipment used to determine an individual’s power output must match that which was used in establishing the normative data with which it will be compared.

Although this study excluded participation from any subject who is part of a varsity athletic team, a large number of the subjects were Kinesiology major students and students in club or recreational sports of the university where the study was conducted. These students likely represent a more active section of their age group than the general population. Additionally, certain assumptions were made on the part of the researchers in order to facilitate the process of data collection and analysis. The first assumption was that subjects followed the specific guidelines given to them. These guidelines included refraining from ingesting CNS stimulating ergogenic supplements such as caffeine or creatine before and during test days. Additionally, subjects were instructed to give maximal effort when performing the test. Another assumption was that subjects were honest when they completed the health history and physical activity level questionnaire.

# PRACTICAL APPLICATIONS

The new WMPT normative reference data using non-racially homogenous healthy young adults established by this study may be more applicable in commercial, research, and educational settings than previously reported values. One application is for strength and conditioning specialists, clinicians, or exercise physiologists who wish to track the pre/post-training outcomes of their clients who engage in explosive movements. Kinesiology major instructors can also use the normative data to demonstrate and/or assess power output and fatigue with their exercise science major students. Additionally, researchers can apply this data to evaluate the effect of a therapeutic intervention on anaerobic capacity. Future research on this topic could utilize the same methodology outlined in this study to validate the findings on power output while incorporating even more anthropometric data for analysis.

# REFERENCES

ACSM. ACSM's guidelines for exercise testing and prescription. Philadelphia, Lippincott Williams & Wilkins, 2013

Ayalon A, Inbar O, Bar-Or O. Relationships among measurements of explosive strength and anaerobic power. In: Nelson RC, Morehouse CA, eds. International Series on Sport Sciences. I: Biomechanics IV. Baltimore, MD; University Park Press; 1974:527-532.

Baker UC, Heath EM, Smith DR, Oden GL. Development of Wingate Anaerobic Test norms for highly-trained females. J Exerc Physiol Online 14: 68–79, 2011.

Bassett, D. (1989). Correcting the Wingate test for changes in kinetic energy of the ergometer flywheel. International Journal of Sport Medicine, 10, 6, 446-449.

Brown, L.E. and Weir, J.P. (2001) ASEP Procedures recommendation I: Accurate assessment of muscular strength and power. Journal of Exercise Physiology Online, 4, 1- 21.

Coppin, E., Heath, E. M., Bressel, E., & Wagner, D. R. (2012). Wingate anaerobic test reference values for male power athletes. International journal of sports physiology and performance, 7(3), 232-236.

Dotan, R., & Inbar, O. (1977, January). 30-sec all-out ergometric test-its reliability and validity for anaerobic capacity. In Israel Journal of Medical Sciences (Vol. 13, No. 3, pp. 326-327). 2 Etzel St. French Hill, Jerusalem 97853, Israel: Israel Journal Med Sciences.

HSU Analytics | Institutional Research, Analytics, and Reporting. (2020, August). Humboldt State University Institutional Research, Analytics, and Reporting. https://irar.humboldt.edu/fast_facts

Haff, G., & Triplett, N. T. (2016). Essentials of strength training and conditioning. Champaign, IL: Human Kinetics.

Harvey, Leonie et al. “The Effect of Previous Wingate Performance Using one Body Region on Subsequent Wingate Performance Using a Different Body Region.” Journal of human kinetics vol. 56 119-126. 12 Mar. 2017, doi:10.1515/hukin-2017-0029

Hermina, W. (1999). The Effects of different resistances on peak power during the Wingate anaerobic test.

Hoffman, Jay. *Norms for Fitness, Performance, and Health*. Human Kinetics, 2006.

Konkel L. (2015). Racial and Ethnic Disparities in Research Studies: The Challenge of Creating More Diverse Cohorts. Environmental health perspectives, 123(12), A297–A302. https://doi.org/10.1289/ehp.123-A297

Maud, P. J., & Shultz, B. B. (1986). Gender comparisons in anaerobic power and anaerobic capacity tests. *British Journal of Sports Medicine*, *20*(2), 51–54. https://doi.org/10.1136/bjsm.20.2.51

Maud, P. J., & Shultz, B. B. (1989). Norms for the Wingate anaerobic test with comparison to another similar test. Research Quarterly for Exercise and Sport, 60(2), 144-151.

Metter, E. J., Conwit, R., Tobin, J., & Fozard, J. L. (1997). Age-Associated Loss of Power and Strength in the Upper Extremities in Women and Men. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 52A(5), B267–B276. https://doi.org/10.1093/gerona/52a.5.b267

National Science Foundation - Where Discoveries Begin. (2017, November 01). Retrieved October 21, 2020, from https://ncsesdata.nsf.gov/herd/2016/

Ramírez-Vélez, Robinson1; López-Albán, Carlos A.2; La Rotta-Villamizar, Diego R.1; Romero-García, Jesús A.1; Alonso-Martinez, Alicia M.3; Izquierdo, Mikel 1,3 Wingate Anaerobic Test Percentile Norms in Colombian Healthy Adults, Journal of Strength and Conditioning Research: January 2016 - Volume 30 - Issue 1 - p 217-225

Robergs, R. A., Kennedy, D., Gibson, A. L., Zuhl, M., Hsu, H. S., Beam, J., ... & Estrada, E. (2015). Evidence for the invalidity of the Wingate test for the assessment of peak power, power decrement and muscular fatigue. Central European Journal of Sport Sciences and Medicine, 10(2), 63-78.

Vargas, N. T., Robergs, R. A., & Klopp, D. M. (2015). Optimal loads for a 30-s maximal power cycle ergometer test using a stationary start. European journal of applied physiology, 115(5), 1087-1094.

Zupan, Michael F1; Arata, Alan W1; Dawson, Letitia H1; Wile, Alfred L1; Payn, Tamara L2; Hannon, Megan E3 Wingate Anaerobic Test Peak Power and Anaerobic Capacity Classifications for Men and Women Intercollegiate Athletes, Journal of

Strength and Conditioning Research: December 2009 - Volume 23 - Issue 9 - p 2598-2604