The Wingate Anaerobic Test: A Comprehensive Literature Review and Update on Reference Values in Athletes

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The Wingate anaerobic test: A comprehensive literature review and update on reference values in athletes.

Caleb Christie

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INTRODUCTION

The Wingate Anaerobic test (WAnT) was developed in the 1970s as a measurement of lower extremity anaerobic power (Ayalon, Inbar, Bar-Or, 1974) and has long been used as a measurement tool in athletes, who are often defined by numbers. While numbers are not able to entirely predict or evaluate athletic ability, they are often used as a tool to predict or rate athletes. The WAnT has long been a gold standard in evaluating lower extremity power, which is a highly valuable aspect of many sprint and power-driven sports (e.g., hockey, football, or track and field). The WAnT was originally developed and performed on a cycle ergometer that includes a subject pedaling for 30 seconds at maximal effort against a predetermined percentage of their body weight (BW), which has stood as the widely accepted method since development. There are multiple variables that can be adjusted at the investigators’ discretion which may influence data output, including percentage of body weight (BW) as resistance, type of ergometer, time of testing in regard to participants’ training macrocycle, duration of the WAnT, and inclusion of a familiarization session. Each of these variables can change the impact of reported data and reliability of a study compared to others. For instance, increasing or decreasing resistance may alter the ability of the participant to produce power efficiently, whereas shortening duration takes the lowest power values away from the calculation, increasing MP. These variables may be manipulated to achieve optimal performance outcomes.

Common indices of the WAnT often include peak power (PP), mean power (MP), anaerobic power (AP), anaerobic capacity (AC), revolutions per minute (RPM), fatigue index (FI), and lowest power (LP). Calculations for these terms were defined by Bringhurst et al. (2020): Peak power is calculated as the highest instantaneous power output achieved in Watts, and MP is calculated as the average power output in Watts over the duration of the test. Anaerobic power is defined as peak power per kilogram (kg) of BM (W/kg), whereas AC is mean power per kg of BW (W/kg). Lowest power is deemed the lowest instantaneous power output recorded during the test in Watts; maximum revolutions per minute can be calculated as the highest instantaneous pedaling cadence, and FI can be calculated as [(PP-LP)/PP] X 100.

The original instructed percentage for resistance on a mechanically braked ergometer (ME) was 4% of the subject’s BW (Ayalon et al., 1974), but subsequent studies measuring WAnT power used percentages between 6-10% of BW (Bar-Or, 1987). Bar-Or (1987) suggested optimal loads for non-athletes at 9% of BW and 10% of BW for adult athletes, but these percentages were based on the Monark ME. However, Coppin et al. (2012) cited further research that determined 8.5% of BW was the optimal load when testing power-trained male athletes. In an effort to respond to individual participants producing higher power outputs at different resistance levels, many researchers have completed practice trials in an effort to individually determine which resistance produces highest values for each participant and completing experimental research with these predetermined percentages (Mougin et al., 1986; Ozkaya et al., 2014; Zouhal et al., 1998).

The WAnT was originally performed on a ME. Technological advancements have introduced electromagnetically braked ergometers (EE) that use electromagnetic flywheel braking systems, generally controlled by a computer interface, instead of the manual application of suspended weights in ME. Before the introduction of the EE and automatic braking systems,
there was a natural delay in the time to reach maximum resistance due to human reaction time in applying the resistance, whereas automatic braking systems allow for instantaneous loading and more accurate recording of all data for the test. With this in mind, the delay time to reach maximum resistance was most likely 2 to 4 seconds, reducing the peak power and possibly the anaerobic capacity because the 30 seconds usually did not start until the final load was reached (Zupan et al., 2009). Most studies performed prior to 1999 report substantially lower peak power and anaerobic capacities than the study by Zupan et al. (2009).

An important part of establishing and standardizing WAnT values and comparing those of athletes to other athletes is time of testing in an athletes’ macro-cycle of training periodization. This is not something that is often included in reviews or discussed, but carries importance when participants are athletes. Methods of investigations often include instructions not to exercise beyond participants’ normal regime at the time. However, “normal regimes” at certain periods of the year are different for athletes in different sports (i.e., collegiate football and track and field). Lifting practices often change dependent on where an athlete is relative to their competitive season; an athlete out of season will be training in an effort to increase speed, strength and power, whereas an athlete that is in their competitive season will be training to maintain what was built in the off-season. Peak power output may significantly differ in individual athletes between mesocycle periods, which reduces reliability of reference values if recorded during different periods. In an effort to investigate the timing of testing in athletes’ macro-cycles, Grobelna et al. (2011) evaluated the effect of the transition period on WAnT indices. Grobelna et al (2011) describes the transition period as “a period of physical and psychological recovery for athletes after the competitive season”. They found significantly better total work output (T2: 159±9.7 J/kg; T1: 157±11.9 J/kg; p=0.03606) and max power (T2: 12.2±0.75 W/kg; T1: 12.0±0.88 W/kg; p=0.03962) in T2 (after transition period) vs T1 (before transition period) in male athletes with no significant changes in body mass or %fat. However, this effect was not seen in female athletes. This data suggests that testing athletes after their respective transition period of a reduction in training volume and intensity produces higher output values. Further, these results show that a transition period does not decrease anaerobic performance parameters.

The WAnT is a physically taxing test and some researchers have investigated the effects of testing protocols with shortened durations. In shorter duration WAnT protocols (e.g., 15- and 20-sec variations), changes in body response and data output must be considered. A previous study has shown that a 10-second reduction of test duration reduces physical discomfort in more than 90% of participants (Attia et al., 2014). Metabolic energy sources are likely altered in shortened WAnTs, too. Anaerobic glycolysis is only an effective means of energy production during short, intense exercise, providing energy for a period ranging from 10 seconds to 2 minutes (Sawczyn et al., 2017). Shortened durations, including the 15- and 20-second duration WAnT, may use more of the phosphocreatine energy system rather than extending into the glycolytic system. Although the 30-second WAnT was developed to assess AP and AC, it has been widely debated what percentage of energy output comes from aerobic pathways towards the latter portion of the test, where estimates of aerobic contribution range from 9-44% (Attia et al., 2014). In terms of WAnT indices, mean power (MP) is expected to be different in shortened WAnTs compared to 30-second WAnT protocols, whereas peak power (PP) should not be statistically different. In a 30-second WAnT, muscular fatigue does not truly affect performance until the second 15-seconds of the test when power output significantly declines. With the
second 15-second portion of the test omitted in 15-second WAnT protocols, the calculation of MP will not include the lowest values, resulting in a larger mean. Consequently, it is difficult to compare data derived from studies of different WAnT durations. There is a limited pool of evidence investigating prediction-based algorithms from shortened WAnTs (Attia et al., 2014), but predictions may not always accurately describe a true 30-second WAnT.

Due to different testing protocols and ergometers, many investigations evaluated the reliability of the WAnT to justify data comparison across studies. Previous research indicates the WAnT is reliable for all types of ergometers, specifically in athletes (Ozkaya et al., 2018; Attia et al., 2014; Malone et al., 2014). Previous studies with multiple tests have also exhibited a familiarization effect between first and second trials (Bringhurst et al., 2020; Ozkaya et al., 2012; Ozkaya, 2013).

While there are many changeable variables associated with the WAnT, repeated measures with the same variables have proven to be reliable. Despite many options for testing the power of athletes, the WAnT is still widely considered one of the best tests. Although the WAnT is a well-established standard of lower extremity power testing, there are slight variations in test administration (e.g., type of ergometer, amount of resistance, duration of warm-up, etc.). Additionally, normative data specific to power-trained athletes is limited. Many WAnT validity and reliability studies included non-athletes or even sedentary persons as study participants, limiting the usefulness of the data. In contrast, WAnT data on athletes can be used in evaluation methods or as predictors of athletic ability. Therefore, the purpose of this review is to comprehensively cover the literature on the WAnT specific to power-trained athletes, noting the power outputs obtained and the variations in the testing procedures.

METHODS

Data Sources

An initial search of articles was conducted using PubMed and Scopus databases with the search phrase [Wingate AND “cycle ergometer” AND athlete] yielding 205 results. Included studies in the review pertained to the WAnT and athletes. Randomized clinical trials, controlled clinical trials without randomization, prospective studies, and cohort studies were the studies of interest.

Study Selection

Inclusion criteria included a WAnT from athletes with data reported (e.g., PP, MP, etc.), excluding studies that did not include a trial or report data (n=78). Studies were excluded if test subjects were not reported as “athletes” (n=91); study samples of physical education students or the general population were excluded. Studies of time trials were also excluded (n=13); only WAnT studies were included. Studies only needed an available abstract to be considered for review as long as they met the inclusion criteria and provided key points of interest to make a presumption related to the purpose. After review, one study was excluded due to a lack of ability to access the full text, resulting in 22 included articles (Table 1).
Although the WAnT was developed many years ago, testing is still not standardized. For example, variations from the 30-second protocol have been used, and the resistance or load applied has varied. One commonly used resistance is 7.5% of BW (0.075 kg/BW), used by most of the investigations in this review. Other investigators used a familiarization or preliminary trial to determine each subject’s optimal resistance for PP output.

Reliability

Reliable testing methods are critical in evaluating power output and relating it to athletics. Without reliable testing methods, data collected would not be useful in comparisons with collected data from other labs or tracking the changes of athletes over a training period. Before ergometer hardware and software upgrades in the 2000s, most power indices were calculated in 5-second means [traditional indices] (Ozkaya et al., 2018), which can lead to large discrepancies in PP as calculated today. For example, 1-second PP of 1500W, 1490W, 1480W, 1470W, and 1460W would lead to a PP<sub>S5</sub> of 1480, whereas millisecond PP would be 1500W. New generation indices, or indices calculated instantaneously, may allow for lower discrepancies in reliability. In addition to changes in software, mechanical changes to ergometers led to higher reliability. The Wingate anaerobic test is a reliable test of AP of athletes, and test-retest reliability has been measured in multiple studies.

Attia et al. (2014) examined test-retest reliability of 30-s and 20-s WAnT using an active recovery period of three minutes following each test. Intraclass correlation coefficient (ICC) for PP and MP were both 0.98 for the 20-s test. For the 30-s test, ICC for PP was 0.95, whereas ICC for MP was 0.90. These numbers suggest that high reliability for both PP and MP may be obtained with a 20-s or 30-s WAnT.

Malone et al. (2014) evaluated reliability across bouts (intra-session) and days (inter-session) of a 30-s WAnT. Athletes completed 2-3 tests in one day, interspersed by 4 minutes of cycling at 80W at 80 revolutions per minute, and repeated 2-3 tests in one day a minimum of 72-hours later. Intra-session ICCs for 2 and 3 bouts for PP and MP were less than observed in the Attia et al. (2014) study, but still strong (>0.7), indicating that PP and MP did not differ significantly from same-day test to test (with 4 minutes of active recovery between tests). Inter-session reliability ICCs were >0.90 for PP and MP for all bouts. Obviously, there will be fatigue-related declines in power measurements for protocols requiring multiple bouts of the WAnT with short rest periods, but this study showed that the decline was not significant when the number of bouts was 2-3.

Test-retest reliability in Wingate testing on athletes once again showed a high ICC (0.99) for PP in a study by Ozkaya et al. (2018), whereas ICC for MP was 0.98. High ICCs were also reported for LP, fatigue index, and power drop based on 5-s means. ICCs for MP, AP, and LP were all above 0.94 [new generation indices].

Duration

Attia et al. (2014) investigated how the data obtained from a 20-second WAnT could be used to predict the traditional 30-second WAnT measures. They concluded that if desired, the
30-second WAnT indices can be predicted accurately from a 20-second test. Significantly greater values for MP (675±118 W) for the 20-second WAnT compared to the 30-second WAnT (612±94 W) suggest that subject performance fell dramatically in the final 10 seconds of the test (Attia et al., 2014). However, the predicted MP (620.5±103.5 W) was similar to measured scores for MP (612.3±97.1 W) [p=0.08].

Sawczyn et al. (2017) investigated differences between three durations of WAnT: 30-seconds, 60-seconds, and 120-seconds, as well as four repetitions of 30-seconds each with recovery intervals of 30-seconds. Investigators found a natural decrease of work volume along with the increase of test duration (on a 30-second basis). During longer anaerobic tests (60-seconds and test 4 of 30-second bouts), higher blood lactate concentrations were observed as compared to 30-second Wingate test (Sawczyn et al., 2017), despite less total work on a per 30-second basis, suggesting a high level of fatigue after the first 30 seconds. The lowest aerobic component of work energy supply in long-term anaerobic tests was noted during 60-second load (Sawczyn et al., 2017). Average peak power during the repeated measures test was measured at 11.3±0.8 W/kg compared to an average 30-second WAnT peak power value of 13.0±1.0 W/kg (Sawczyn et al., 2017).

Grobelna et al. (2011) used a shortened 15-second test, allowing for the measurement of maximal AP while avoiding the acute effects of fatigue caused by the full-length 30-second test. In comparison to reference values produced by Zupan et al. (2009) and Coppin et al. (2012), the highest PP results from Grobelna et al. (2011) ranked as below average and low, respectively, for men, and as above average for women according to Zupan et al. (2009). When ranked with consideration of BW, results from Grobelna et al. (2011) rank as average and low according to Zupan et al. (2009) and Coppin et al. (2012), respectively, for men, and above average for women according to Zupan et al. (2009).

**Resistance**

Resistance values differ across investigations and across methodologies used. The most used resistance for traditional WAnT performed on a cycle ergometer was 75 g/kg or 7.5% of the participants’ BW (Bell & Cobner, 2007; Bell & Cobner, 2011; Kikuchi et al., 2017; Legaz-Arrese et al., 2011; Potteiger et al., 2010; Zupan et al., 2009). Grobelna et al. (2011) used a lower percentage at 7%, whereas others used increasingly higher percentages of BW. Brinthurst et al. (2020) and Coppin et al. (2012) each used 8.5% of BW or 85 g/kg, whereas Scott et al. (1991) and Ozkaya et al. (2009) used 9% or 90 g/kg, Nioka et al. (1999), Ozkaya (2013), Ozkaya et al. (2018), and Penkunlu et al. (2016) all used 10% of BW or 100 g/kg. In three reported studies by Zouhal et al. (1998), Mougin et al. (1996), and Ozkaya et al. (2014), each individual participant had a different workload. In these studies, participants completed WAnTs before collecting data to determine each participants’ optimal workload, which was later used in data collection.

**Familiarization trial**

Due to the nature of the WAnT, not many sport movements are similar. Most sports involve running, not cycling. Many athletes have not used an ergometer, let alone a bike, in years before participating in testing. For this reason, many studies have investigated the effect of a trial run or familiarization session by comparing data between first and second trials. Studies have
consistently exhibited learning effects from a familiarization trial as depicted in larger PP and MP outputs.

Bringhurst et al. (2020) showed high test-retest reliability of the WAnT with significant ICCs between trials for PP and MP (0.957 and 0.973, respectively). If their familiarization trial data is included, those ICCs drop to 0.847 (PP) and 0.829 (MP). Club hockey players increased MP and PP from a practice trial to T1 but remained stable from T1 to T2. However, there was no difference across trials in recreational players. These results suggest that a practice or familiarization trial is necessary for most consistent and reliable data in athletes.

Ozkaya (2013) found significant familiarization effects in all mechanical power outputs from T1 (pre-familiarization) to T2 (post-familiarization) to T3 (retest) of both an elliptical WAnT and a cycle WAnT. ICC analyses also indicated fair and moderate agreements between T1 and T2. After familiarization sessions, ICCs between T2 and T3 increased to moderate and high-level correlations for both the elliptical (between 0.74 and 0.91) and the cycle (between 0.76 and 0.93) WAnTs, suggesting significant learning effects from the first to second trials (p ≤ 0.001). At least one familiarization trial is key in maintaining accurate and reliable WAnT data.

CONCLUSION

Wingate anaerobic testing is considered a gold standard for lower extremity power testing in athletes. However, variations in how the test is administered make it difficult to compare results across studies. Also, there is lack of research completed on female athletes, which should be included in an effort to establish reference values for athletes. Despite testing protocol variations, this review identified some parameters that may be recommended for optimal WAnT output. A familiarization trial is proven to be key in establishing reliable data and should be included in WAnT protocols. Previous research has determined optimal testing loads to range from 7.5-10% of BW, but recent research has demonstrated an optimal testing load at 8.5% of BW for athletes. Preliminary trials can help determine individual optimal loads for PP output, but this may make it difficult to standardize the test or generalize the results to reference values. As originally developed, the 30-second WAnT elicits the glycolytic energy system and provides a valid measurement for mean power. Shortened WAnT should not be included in reference values unless only investigating PP, AP or RPM, as PP and RPM should be reached in the first 5-10 seconds of a test. Shortened WAnT studies investigating MP, AC, FI, or LP should not be included in reference values due to the loss of valuable data in the final 10-15 seconds of the WAnT. Current technological updates involving EE allow for instantaneous measures and therefore should be used when available compared to ME. Previous research investigating differences between ME and EE suggest moderate correlations and consistency between ergometers, but also found differences in key indices between ergometers (Astorino & Cottrell, 2011; Mickelwright et al., 2006). Therefore, additional WAnT reference values need to be established for athletes tested on EEs. Lastly, until further research investigating testing differences between mesocycle periods is introduced, testing should take place after the transition period, as previously determined that PP values were higher following the transition period compared to before the transition period (Grobelna et al., 2011). This applies under the
implication of comparing values to those of other athletes; WAnT may be performed during any
mesocycle with evaluation methods focused on individual comparisons.

**PRACTICAL SIGNIFICANCE TO ATHLETIC PERFORMANCE**

The WAnT can be used to track changes in an athlete’s AP and AC. Such data can be
used to evaluate the effectiveness of a training program or the effect that a certain phase of
periodization has on an athlete’s power production. Thus, an athlete’s training program can be
refined by periodic WAnT testing.

Comparing an athlete’s WAnT to normative data helps the athlete and coaching staff
gauge one’s AP relative to other athletes. These normative values can be motivating factors for
returning to sport from injury, goal setters for power training, or benchmarks in comparing one
team to another. Data from this summary provide a reference for athletes and coaches.

Power values may be a predictor of athletic ability, particularly in sports in which AP is
essential to success. While numbers do not always translate to game day ability, exercise science
professionals and coaches can use WAnT results to help evaluate the AP of their athletes.
Measurable performance metrics are often used for athletic evaluation. For instance, the NFL
combine is a series of measurable anthropometric and performance variables, including arm
length/hand size, 40-yard dash, vertical jump and many other characteristics. Similarly, the
WAnT can be used as an evaluative tool in sports in which AP is of primary importance, such as
ice hockey, short track speed skating, wrestling, sprint cycling, etc.
References


Table 1. Summary of key characteristics.

<table>
<thead>
<tr>
<th>Author &amp; Year</th>
<th>Number of Subjects</th>
<th>Athletes Represented (number, sex, sport or position)</th>
<th>Ergometer Used for Wingate</th>
<th>Wingate Duration</th>
<th>Mean ± SD of PP</th>
<th>Mean ± SD MP</th>
<th>Main Findings/Take Home</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attia A, Hachana Y, Chaabene H, Gaddour A, Neji Z, Shephard RJ, Chelly MS. (2014)</td>
<td>81</td>
<td>Male team-sport athletes (soccer, basketball, rugby, and handball)</td>
<td>Monark 894 E Peak Bike (Weight Ergometer, Vansbro, Sweden)</td>
<td>20- &amp; 30- seconds</td>
<td>30sec: Trial 1: 991 ± 151 W</td>
<td>30sec: Trial 1: 595 ± 61 W</td>
<td>Residual data for WAnT20 and WAnT30 test and retest were normally distributed, with no significant differences between test and retest outcomes for WAnT20 or WAnT30. The PPO and MPO values satisfied the ICC criterion of high relative reliability, and this was confirmed by SWCs values that were larger than their SEMs counterparts. Results demonstrated that the WAnT20 is a reliable tool for the evaluation of the anaerobic performance of the legs in male team sport athletes. Furthermore, it appears that if desired, the traditional WAnT30 indices can be predicted accurately, using data collected during the WAnT20.</td>
</tr>
<tr>
<td>Bell W, Cobner DM. (2007)</td>
<td>41</td>
<td>Male University Rugby union Football players</td>
<td>Monark 864 (Varberg, Sweden)</td>
<td>30 seconds</td>
<td>1154 ± 246 W</td>
<td>X</td>
<td>A low but significant negative correlation was found between PPO and the time taken to reach PPO, confirming the view that the earlier the time to PPO the larger the value of PPO. Since the proposal does not involve changes to the original individual values of PPO, MPO, or minimal power output, it can be used with any data set irrespective of the nature of the sample, equipment or protocol employed.</td>
</tr>
<tr>
<td>Bell W, Cobner D. (2011)</td>
<td>53</td>
<td>Male Rugby Union players (club and University level)</td>
<td>Monark 864 (Varberg, Sweden)</td>
<td>30 seconds</td>
<td>1216 ± 256 W</td>
<td>X</td>
<td>The negative correlation between velocity and acceleration was highly significant and complementary. The distance curve increases sharply to PPO, followed thereafter by a gradual decline in power output.</td>
</tr>
<tr>
<td>Brighurst RF, Wagner DR, Schwartz S. (2018)</td>
<td>21</td>
<td>Male hockey players, 10 University club/11 adult recreation league</td>
<td>EE Velotron Dynafit Pro (RacerMate, Seattle, WA, USA)</td>
<td>30 seconds</td>
<td>Club: 1303 ± 163 W (15.35 ± 1.37 W/kg) Rec: 1186 ± 231 W (13.79 ± 1.33 W/kg)</td>
<td>Club: 834 ± 103 W (9.82 ± 0.73 W/kg) Rec: 718 ± 79 W (8.49 ± 1.34 W/kg)</td>
<td>Extremely high reliability was found between trials after excluding the practice trial for MP, anaerobic power and anaerobic capacity. A single practice trial followed by one WAnT is sufficient because multiple WAnTs do not result in higher power outputs; after the initial familiarization trial, the WAnT is reliable.</td>
</tr>
<tr>
<td>Coppin E, Heath EM, Bressel E, Wagner DR. (2012)</td>
<td>77</td>
<td>Male NCAA athletes (American football or power event in track and field)</td>
<td>Monark 894 E (Monark, Sweden)</td>
<td>30 seconds</td>
<td>1084.2 ± 137.0 W (12.9 ± 1.5 W/kg)</td>
<td>777.1 ± 80.9 W (9.3 ±0.9 W/kg)</td>
<td>The reference values developed in this study can be used in various athletic training and research programs to more accurately assess athletes’ anaerobic fitness. Reference values from the current study may also be used by coaches and athletes to help determine success in power sports and to monitor progress of anaerobic-training programs for male athletes.</td>
</tr>
<tr>
<td>Grobelna J, Borkowski J, Kosendiak J. (2012)</td>
<td>16</td>
<td>Sprinters (6 women, 10 men) who specialize in the 100-200 and 400m sprint distances</td>
<td>824E Ergomedic ergometer (Monark, Sweden)</td>
<td>15 seconds</td>
<td>Males: T1: 851 ± 88.9 W (12.0 ±0.88 W/kg); T2: 853 ± 76.5 W (12.2 ±0.75 W/kg) Females: T1: 656 ± 76.0 W (10.5 ± 1.14 W/kg); T2: 654 ± 102.2 W (10.5 ± 1.26 W/kg)</td>
<td>X</td>
<td>When comparing pre- to post-transition period performance in females, there were no significant changes in total work output (Wtot) and maximal power (Pmax). However, these parameters’ ratios to body weight were found to significantly increase in the group of males from pre- to post-transition period. The males’ increase in Pmax in relation to body mass and the increase in the number of revolutions, with no change in Tr or Tm, indicate speed improvement during the relatively short power output measured in this study. The four to five week-long transition period did not diminish power and work performance in 15-second maximal power output test in young sprint athletes.</td>
</tr>
</tbody>
</table>
The mean and peak power values from the 2 anaerobic performance tests did not differ between groups based on the A-allele recessive model of MCT1 T1470A genotype in wrestlers. Additionally, the 2 anaerobic performance tests revealed no significant differences in mean and peak power values or blood lactate concentrations between national-level (n = 30) and international-level wrestlers (n = 16). In addition, wrestlers with the MCT1 AA genotype had lower blood lactate concentrations during 2 anaerobic performance tests than wrestlers with the TA or TT genotype.
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Equipment</th>
<th>Familiarization</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mougin F, Bourdin H, Simon-Rigaud ML, Didier JM, Toubin G, Kantelip JP. (1996)</td>
<td>Male athletes</td>
<td>Monark 814E with weights</td>
<td>30 seconds</td>
<td>After reference night: 731.62 ± 55.38 W (10.71 ± 0.83 W/kg) After delayed bedtime (less sleep): 750.46 ± 62.5 W (10.79 ± 0.68 W/kg)</td>
<td>Bout 1: 1629.1 ± 215.0 W</td>
<td>Bout 2: 1723.6 ± 261.5 W</td>
<td>Bout 3: 626.3 ± 83.7 W</td>
</tr>
<tr>
<td>Nioka S, Moser D, Lech G, Evengelisti M, Verde T, Chance B, Kuno S. (2009)</td>
<td>Male sprinters from the University of Penn Track team (events: high jump, pole vault, decathlon, long jump, 100m, 200m, 400m, 800m)</td>
<td>Monarch (Model 184E)</td>
<td>30 seconds</td>
<td>774 ± 86 W</td>
<td></td>
<td></td>
<td>32</td>
</tr>
<tr>
<td>Ozkaya O. (2013)</td>
<td>Male athletes (basketball, football, ice hockey, rugby)</td>
<td>Monark 894 (Varberg, Sweden)</td>
<td>30 seconds</td>
<td>WAT: Pre-familiarization (Trial I): 9.8 ± 1.0 W/kg Post-familiarization (Trial II): 11.8 ± 1.0 W/kg Trial III (Retest Trial III): 12.2 ±1.1 W/kg</td>
<td>WAT: Pre-familiarization (Trial I): 8.2 ± 0.7 W/kg Post-familiarization (Trial II): 8.7 ± 0.7 W/kg Trial III (Retest Trial II): 8.9 ± 1.9 W/kg</td>
<td>The Wingate test for maximum anaerobic testing exhibited a greater desaturation of hemoglobin/myoglobin of the vastus lateralis muscle on the cycle. The average deoxygenation of the muscle at the end of exercise was 80.2 ± 12.2%, much higher than that in the VO2max test. The onset of the deoxygenation occurred promptly at the beginning of exercise. The sprinters had over 3 times higher work output at their anaerobic maximum capacity, than that of aerobic maximum capacity.</td>
<td>20</td>
</tr>
<tr>
<td>Ozkaya O, Balci GA, As H, Vardarli E. (2018)</td>
<td>Male athletes (basketball, football, tennis, or track and field)</td>
<td>Monark Peak Bike 894 (Monark, Vansbro, Sweden)</td>
<td>30 seconds</td>
<td>Session 1: 1169.35 ± 142.57 W</td>
<td>Session 2: 1169.35 ± 142.57 W</td>
<td>Session 3: 1165.15 ± 142.16 W</td>
<td>The main results showed that there were significant familiarization effects in all mechanical power outputs obtained from Trial I and Trial II of EAT and WAT (p ≤ 0.001). After familiarization sessions, reliability coefficients between Trial-II and Trial-III showed moderate to strong-level agreements for both EAT (ICC = 0.74-0.91) and the WAT (ICC=0.76-0.93). Results suggested that prior to the performance tests, combination of a well-designed familiarization session with one full all-out test administration is necessary to estimate the least moderately reliable and accurate test indices for both WAT and EAT.</td>
</tr>
<tr>
<td>Ozkaya O, Colakoglu M, Fowler D, Kuzucu OE, Colakoglu S. (2009)</td>
<td>Healthy male university athletes</td>
<td>Monark 834 (Varberg, Sweden)</td>
<td>30 seconds</td>
<td>Ergometer: 878.9 ± 162 W</td>
<td>Ergometer: 648.5 ± 82 W</td>
<td></td>
<td>The WAnTet gave higher AP and PP outputs. Additional evidence supporting increased anaerobic contribution by glycolytic sources during WAnT was the higher ΔLa values from performance on the WAnT versus lower ΔLa values when performed on the WAnTc. Higher anaerobic explosive power and capacity was measured in male university athletes performing the WAnT on a modified elliptical trainer compared to similar testing on a traditional cycle ergometer.</td>
</tr>
<tr>
<td>Ozkaya O, Colakoglu M, Kuzucu EO</td>
<td>Male team sport players (football, ice-hockey and rugby)</td>
<td>Monark 894 (Varberg, Sweden)</td>
<td>30 seconds</td>
<td>Cycling Wingate all-out test (WAT): 11.2 ± 0.98 W/kg</td>
<td></td>
<td>WAT: 8.67 ± 0.67 W/kg</td>
<td>The main results showed that there was significantly less aerobic and more anaerobic contribution in EAT compared with WAT. In addition, a significantly greater relative contribution of the phospholytic system was shown in EAT.</td>
</tr>
<tr>
<td>Delextrat A.</td>
<td>2014</td>
<td>Male athletes from different sport disciplines</td>
<td>Monark 894E Peak Bike Ergometer (Monark, Varsbro, Sweden)</td>
<td>30 seconds</td>
<td>14.7 ± 1.3 W/kg</td>
<td>x</td>
<td>Drop in mechanical work (DMW) might be used as a reliable output to evaluate fatigue-related power data of the anaerobic capability. DMW yielded the highest ICC over fatigue index and power drop when calculated based solely on PP and MP data.</td>
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<tr>
<td>Pekunlu E, Ozkaya O, Yapicioglu B.</td>
<td>2016</td>
<td>21</td>
<td>Divison 1 Men's hockey athletes (forward, defense)</td>
<td>Monark 894E</td>
<td>30 seconds</td>
<td>1305.5 ± 177.2 W (14.7 ± 1.5 W/kg)</td>
<td>842.8 ± 92.4 W (9.5 ± 0.6 W/kg)</td>
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<tr>
<td>Potteiger JA, Smith DL, Maier ML, Foster TS.</td>
<td>2010</td>
<td>21</td>
<td>Free-style wrestlers of national and international level of middleweight category, aged 19-28 years, having engaged in sports training for 5-13 years</td>
<td>Monark 824E ergometer</td>
<td>30/60/120 seconds</td>
<td>13.0 ± 1.0 W/kg</td>
<td>x</td>
</tr>
<tr>
<td>Sawczyn S, Lusenko ON, Mishchenko VS, Pasek M, Domowski M.</td>
<td>2017</td>
<td>34</td>
<td>4 distance runners (D; 3000m +) 5 middle distance runners (MD; 800-1500m) 3 sprinters (S; 200-400m)</td>
<td>Modified Monark ergometer</td>
<td>30 seconds</td>
<td>D: 13.2 ± 0.66 W/kg MD: 13.8 ± 0.50 W/kg S: 14.2 ± 0.83 W/kg C: 13.3 ± 1.05 W/kg</td>
<td>x</td>
</tr>
<tr>
<td>Scott CB, Roby FB, Lohman TG, Bunt JC.</td>
<td>1991</td>
<td>16 (12 athletes, 4 control)</td>
<td>7 male sprinters competing in sprint running (S) [100, 200 and 400-m races] and 6 untrained men (UT)</td>
<td>Ergomeca bicycle</td>
<td>30 seconds</td>
<td>Sprinters: 1111 ± 38 W (15.9 ± 1.2 W/kg) Untrained: 886 ± 148 W (13.4 ± 2.9 W/kg)</td>
<td>Sprinters: 822 ± 37 W (11.8 ± 0.7 W/kg) Untrained: 646 ± 69 W (9.8 ± 2.0 W/kg)</td>
</tr>
<tr>
<td>Zouhal H, Rannou F, Gratias-Delamarche A, Monnier M, Bentue-Ferrer D, Delamarche P.</td>
<td>1998</td>
<td>13 (7 athletes, 6 untrained)</td>
<td>NCAA Div 1 athletes (lacrosse, gymnastics, sprint cycling, football, baseball, tennis,</td>
<td>Monark 824E or 874E weight ergometer</td>
<td>30 seconds</td>
<td>Men: 951 ± 141 W (11.65 ± 1.39 W/kg) Women: 598 ± 88 W (9.59 ± 0.99 W/kg)</td>
<td>Men: 686 ± 91 W (8.47 ± 0.88 W/kg) Women: 445 ± 64 W (7.16 ± 0.70 W/kg)</td>
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</tbody>
</table>
Hannon ME. (2009) track); Men (n=457), Women (n=64) average, fair, and poor. It was found that the FI was inversely related to peak power.