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Åstrand-Rhyming and YMCA: A Compare and Contrast Literature Review of Two Submaximal Cycle Ergometer Tests

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Abstract

In the world of exercise prescription there are two major protocols that are used to test an individual's aerobic capacity at a submaximal intensity using a stationary bicycle. These protocols require participants to exercise at a constant work rate until a specified hear rate is reached. Data can then be analyzed to determine the participant's aerobic capacity. The objective of this literature review is to look at these two tests – the Åstrand-Rhyming cycle ergometer test (ARCET) and the YMCA cycle ergometer test – and determine if one is better than the other for different populations and which one an exercise professional should choose when working with patients. The literature that is currently out there has validated both tests as good predictions for aerobic capacity when compared to a full maximal exertion test. A primary area that both tests fall short in is predicting aerobic capacity in ethnicities other than those that were used to build the protocol during development. This typically causes a higher error in prediction for populations such as African-Americans compared to Caucasian populations. Although there is little research directly comparing the two tests together, the current literature points towards the YMCA test having a higher degree of accuracy in its predictions when compared to the ARCET. However, either test can be used in a fitness or clinical setting to predict a patient's aerobic capacity with the knowledge that there will be some degree in error.

Introduction

The impetus that sparked the interest in pursuing this subject came from a conversation with a professor about the change in the curriculum of a course on exercise testing procedures. In previous years, the Young Men's Christian Association's (YMCA) submaximal cycle ergometer protocol was the standard test that was taught during the laboratory portion of the exercise testing course. A recent change in the American College of Sports Medicine's (ACSM) Guidelines for Exercise Testing and Prescription textbook lead to a change in the course curriculum. The new test that was being taught was the Åstrand-Rhyming submaximal cycle ergometer test (ARCET) which was developed by Swedish researchers in 1954. The question became: Why did ACSM make this change from the YMCA test to the ARCET, and what impact does it have going forward on the world of exercise prescription? After some communication with the senior editor, Deborah Riebe, of the 10th edition of the aforementioned textbook from ACSM, it was learned that the change was not exactly made in the first place. The YMCA has stopped providing permissions to other entities that would allow them to print their normative data and figures. The YMCA test can still be found in the ACSM's textbook, but figures and data are no longer shown. Although this is the case, the second question previously posed remains valid, although slightly modified: Will the decision made by an exercise professional to choose to use one test over another have any impact, and is one test better for a certain population over another?

In the world of exercise testing and physiology, the VO_{2max} test is the foremost measurement for determining an individual's aerobic capacity (Riebe, Ehrman, Liguori, & Magal, 2018, p. 81). This test measures the maximum volume of oxygen that can be taken in, dispersed throughout the body, and utilized by muscles that are being actively used in various movements

during physical activity. The prominence of the VO_{2max} test comes from its ability to accurately assess the current fitness status of an individual, as well as effectively influence training programs that are designed to increase a person's aerobic fitness.

While there are many benefits to conducting or undergoing a true VO_{2max} test, there are certain instances in which the negatives outweigh the positives. Exercising to complete volitional exhaustion is not only physically difficult, but mentally rigorous as well due to the incredibly high level of determination required to reach that point. Thus, the average individual may be unable to complete the full VO_{2max} test in a safe and effective way that results in reliable data. VO_{2max} tests are also equipment-intensive. Well-equipped labs with metabolic carts, treadmills, EKG leads, and other tools are typically required to properly run the test. With all of these obstacles considered, researchers in the 1950's started thinking about ways to achieve similar results in a less expensive and formal environment (Åstrand & Rhyming, 1954). Out of this process, submaximal aerobic capacity testing was created. Submaximal aerobic testing allows researchers to monitor and record how heart rate(HR) interacts with specific levels of resistance. Ideally, as resistance of an activity increases, the HR should respond accordingly with an increase of its own to keep up with the body's demands. This information can then be placed into a previously established nomogram (Åstrand & Rhyming, 1954), or extrapolated out to the patient's age-predicted maximum heart rate (Golding, Myers, Sinning, 1989).

The Åstrand-Rhyming Submaximal Cycle Ergometer Test

As a PhD student in Sweden, Per-Olof Åstrand began to conduct maximal exercise tests in the 1950's and 1960's on males and females (Lamberts, 2009). Performance testing was relatively new at this point, but had been gaining popularity since the early years of the 20th century due to work done by English physiologist Archibald Vivian Hill in 1924 in an attempt to describe how oxygen and muscles interact during bouts of exercise (Hill, Long, & Lupton, 1924; Lamberts, 2009) Released in the *Journal of Applied Physiology* in 1954, Swedish physiologist, P.O. Åstrand and his future wife, Irma Rhyming, released a "Special Communications" article that established a nomogram that was able to predict VO_2 max values from HR data obtained during a submaximal test. The idea for this test was born out of the need to assess maximal aerobic capacity in individuals who were not able to reach a maximal workload (Åstrand & Rhyming, 1954; Lamberts, 2009). Some reasons for an individual's inability to reach maximum exertion during an exercise test include clinical considerations, age-limiting factors, cardiorespiratory disease, and many others. On the other side of the health and wellness spectrum, maximal exertion exercise tests could also interfere with the regimented training schedules of all types of athletes (Lamberts, 2009).

The cycle ergometer (CE) test that was developed by Åstrand and Rhyming is considered a single-stage test with periodic increases in resistance if HR is below 120 beats per minute (Riebe et al., 2018, p. 87; Åstrand & Rhyming, 1954). The test lasts a total of six minutes and requires that the participant maintains a pedal rate of 50 revolutions per minute (Riebe et al., 2018). The ACSM's Guidelines for Exercise Testing and Prescription (2018) notes that a record of two HRs – taken during minute 5 and 6 of the test – are averaged together to use in the

nomogram created by Åstrand and Rhyming (1954). There are parts of the Åstrand-Rhyming cycle ergometry test (ARCET) that make it more difficult to ensure accuracy than other tests. For example, suggested work rate is based not only on the gender of the participant, but also the fitness status of that person (Riebe et al., 2018). The two categories for each gender are defined as unconditioned or conditioned. A conditioned individual will work at a higher work rate than their unconditioned peer of the same gender. Also, a correction factor must be applied to the individuals VO_{2max} results from the nomogram based on their age (Riebe et al., 2018, p. 81; Åstrand & Rhyming, 1954).

One of the goals that Åstrand had for this test when he and Rhyming developed it back in the 1950's was to obtain accurate aerobic capacity data without having to be in a laboratory setting with high-end equipment (Åstrand & Rhyming, 1954). This ability to run the ARCET outside of a laboratory setting is a major strength of the test. It allows people in the field to assess and track the aerobic capacity of their patients in more comfortable and accessible environments. This strength of the test leads to one of its primary weaknesses. Due to the fact that a submaximal test is not a true maximal test for aerobic capacity, "derived measures will always be by definition compromise measures…" (Macsween, 2001). In this article by Macsween (2001) the idea that without a true maximal exertion test being run for aerobic capacity, the accuracy is compromised, and a margin of error will be incorporated. Since the ARCET nomogram was released in 1954, there has been a large volume of research that has been published verifying the validity of the ARCET for use in clinical and fitness settings (Astrand & Rhyming, 1954; Keren, Magazanik, & Epstein, 1980; Hoehn, Mullenbach, & Fountaine, 2015; Siconolfi, Cullinane, Carleton, & Thompson, 1982).

Keren et al. (1980) found that when a VO_{2max} test was performed via uphill treadmill running (Bruce protocol), results were 6% higher than VO_{2max} values obtained from a maximal step, maximal CE, and predictive modified ARCET. The modification of the ARCET had the participants cycle in three successive stages of increased workload, each of which lasted five minutes with expired air being collected in the final thirty seconds of each stage (Keren et al., 1980). This shows that changes in modalities can have an effect on the VO_{2max} results. In the end, Keren et al. (1980) determined that the modified ARCET was a reliable test for predicting $VO_{2max.}$

In 2015, Hoehn et al. validated the ARCET against a maximal CE test using 10 males and 13 females of college age, the latter of the two being heavily underrepresented in previous aerobic capacity studies such as this. The researchers found that the results between the maximal CE and submaximal ARCET test were not significantly different for the female population (Hoehn et al., 2015). However, in the male population, VO_{2max} was underpredicted by 2.41 ± 3 ml/kg/min, which is "within previously established acceptable ranges for submaximal VO_{2max} tests" according to Hoehn et al. (2015).

Although the protocol is not a perfectly accurate assessment, most researchers have deemed the test suitable for predicting VO_{2max} values, especially when the more complicated and equipment-intensive true VO_{2max} test is not possible for reasons mentioned earlier. ARCET has been used for many years since its release in 1954 and has been modified a number of times to better fit the type of research being done (Keren et al., 1980; Siconolfi et al., 1982). According to the history of submaximal testing described by Robert Lamberts (2009), there had not been much development in the CE submaximal test since Åstrand and another test known as the Physical Work Capacity (PWC) 170 test. These tests were developed in 1954 and 1970 respectively,

meaning that no big innovations had occurred in the thirty-nine years prior to his writing. This lack of "development and specialization" (Lamberts, 2009) in the submaximal CE test is unlike that of the submaximal walking and running tests. For example, ARCET helped to inspire the development of the 6-minute walk test for cardiac and pulmonary patients as well as the Rockport test (Lamberts, 2009).

The ARCET has been a highly regarded protocol since its release in 1954. It has become the basis for many other tests using a variety of different protocols to assess an individual's aerobic capacity at a submaximal level. Many studies over the years have set out to validate the protocol within a multitude of different populations, different settings, and with different research goals. Whether the ARCET was being validated against a maximal treadmill or cycle ergometer test (Keren et al., 1980; Hoehn et al., 2015), or modified to better test the hypotheses for a specific research goal (Siconolfi et al., 1982), the test has been proven to be valid. This shows that the ARCET can be reliably used to determine an individual's aerobic capacity without taking them to maximal exertion.

The YMCA Submaximal Cycle Ergometer Test

First described in the book *Y's Way to Physical Fitness in 1989*, the YMCA submaximal cycle ergometer test was not originally used for predictive VO_{2max} testing (Beekley, Brechue, Dehoyos, Garzarella, Werber-Zion, & Pollock 2004; Garatachea, Cavalcanti, García-López, Gónzalez-Gallego, & de Paz, 2007). Beekley et al. (2004) describe the initial development purpose of the YMCA test as a way to predict physical working capacity (PWC). PWC is defined as the workload at which an individual's maximum HR is obtained.

The YMCA test is a multi-stage test that consists of two to four three-minute stages of increasing workload at a pedal rate of fifty revolutions per minute (rpm) (Riebe et al., 2018; Golding et al., 1989). The first stage of the protocol is extremely important for ensuring that the rest of the test is executed properly. Stage one consists of a 0.5 kg resistance applied to the CE and the participant maintaining the 50-rpm standard (Riebe et al., 2018; Golding et al., 1989). Based on the individual's HR at the end of the three-minute stage, the subject will be put into a bracket that will set the stage two workload at a specific value and then gradually increased until the termination of the test due to time or upon reaching the predicted HR max (Riebe et al., 2018; Golding et al., 1989).

The protocol that can be found in the ACSM's Guidelines to Exercise Testing and Prescription textbook has been modified from the original 1989 protocol published in *Y's Way to Physical Fitness*. The editors of *Y's Way to Physical Fitness* mention that there exists a linear relationship between an individual's HR and the work that their body is performing through exercise (1989). What is intended to elevate the YMCA submax CE test as the superior test over ARCET and the PWC 170 is the understanding that this linear relationship doesn't occur until after a HR of 110 beats per minute(bpm) is achieved. Golding et al. (1989) specify that this ensures external stimuli have a negligible effect on an individual's HR. Some examples that were given of external stimuli that would have an effect at low HRs were laughing, talking, and potentially nervousness that brings on trembling or autonomic nervous system responses. To avoid this disturbance in HR, the YMCA CE, as described in *Y's Way to Physical Fitness* requires a beginning HR of 110 bpm for the data extrapolation portion of the test (Davis, 2004; Golding et al., 1989). The ACSM modified this portion of the test by no longer requiring a beginning HR of 110 bpm for

the data extrapolation (Riebe et al., 2018; Davis, 2004). Two separate studies found that the ACSM modification of the YMCA CE significantly overestimated VO_{2max} by 28% and 26% (Swain & Wright, 1997; Greiwe, Kaminsky, Whaley, & Dwyer, 1995).

In 2004, Beekley et al. conducted a validation study of the YMCA CE test as it was presented in *Y's Way to Physical Fitness* in 1989. The tests that the protocol was validated against were a maximal treadmill test (Bruce Protocol), as well as a maximal CE test (modified Åstrand-Saltin) which were both multi-stage tests of increasing intensity. According to the results from Beekley et al. (2004), even though the YMCA protocol was not developed to be a predictive submax test for treadmill VO_{2max}, it was shown to be an effective measure. There was no significant difference or impact between the genders in this study, however, there was a "slightly greater prediction variation error in men" (Beekley, 2004).

A few years later, in 2007, Garatachea et al. found the opposite impact on submax VO_{2max} predictions than Beekley et al. found in 2004. As mentioned previously, Beekley et al. found that the data showed a worse prediction of VO_{2max} from the YMCA CE test than it did in women. In the Garatachea et al. study (2007), females were overestimated by 11.8% on average while males were overestimated by only 5.4% on average. Although both studies produced opposite data on which gender the test was more accurate in predicting, both studies were able to validate the YMCA CE test as a reliable predictor of actual VO_{2max} values.

Neither of the studies mentioned previously left the YMCA CE test without some questions about its validity as more research came out in the future. One reservation about the YMCA CE is discussed in an article from Jamnick, By, Pettitt, & Pettitt (2016). This refers to the accountability for demographics in the YMCA CE test. Their research was aimed at creating a

custom submaximal exercise test that would include previously established demographic data in the domain of exercise response. The protocol that the team created, known as the Mankato submaximal exercise test (MSET), was also designed to take participants above their gas-exchange threshold. The demographic data that Jamnick et al. gathered was built into the individualized protocol for each participant. The individual participant protocols based on demographic data allowed the team of researchers to make better and more accurate decisions about how to prescribe their submaximal test to each participant (Jamnick et al., 2016). The results of the study showed that the MSET produced results that were more valid than the results from the YMCA test when estimating VO_{2max}.

The YMCA CE has quickly grown in popularity over the years since it was released in 1989. Since the test requires very little equipment, and a flowchart-like guide is provided to the exercise specialist who is running the test, the YMCA CE is very accessible and also well-researched. Beekly et al. (2004) and Garatachea et al. (2007) were both able to effectively validate the protocol as an accurate submaximal assessment of a full VO_{2max} test. Modifications of the YMCA CE, including the one done by the ACSM, have been devised over the years to tailor the test to the population involved, but the standard protocol is still widely used 30 years after its publishing.

A Compare and Contrast of the Two Tests

The literature reviews encompassing research from both the YMCA CE and the ARCET tests have been presented. This section will cover research that evaluates both tests. In cases that there is no information to present on a topic due to its lack of existence or relative obscurity, a note will be made.

Unlike the ARCET, the YMCA submaximal cycle ergometer test does not use an established nomogram to predict VO_{2max}. Instead, an extrapolation method is used to analyze the data by recording the individual's heart rate at two distinct workloads, graphing them on an x-y plane to form a linear relationship, and then continuing that line out to the point at which their age-predicted heart rate max is reached (Beekley et al., 2004; Garatachea et al., 2007). At that point, a line can be drawn vertically down to the x-axis where a host of data including workload, maximum oxygen uptake, Kcal used, and approximate MET level can be found and matched up with the individual's results (Golding et al., 1989).

Although both tests have been validated against a VO_{2max} test on several occasions (Åstrand & Rhyming, 1954; Beekley et al., 2004; Hoehn et al., 2015; Garatachea et al., 2007), neither test is perfect for every population that it intends to test. In essence, both the YMCA CE and ARCET have been shown to fall within acceptable ranges for validity for a submaximal test, but still are prone to both over-predicting and under-predicting results of the full VO_{2max} test (Davis, 2004). Due to the age of the ARCET compared to the YMCA CE test, there have been more studies focused on the ARCET over the years since it has been developed. With the increasing popularity of the YMCA test since its debut in 1989, more research teams have taken the time to study the test in relation to its accuracy in predicting VO_{2max} values. However, what appears to be a problem for both of these testing protocols is their tendency to not perform as well when used for population groups that were not included when the test was originally developed.

Vehrs and Fellingham (2006) sought to investigate this idea in their article. The article the researchers noted,

> To the best of our knowledge, submaximal exercise tests designed to estimate VO2max or VO2peak have typically been developed from samples of White men and women and rarely have a diverse ethnic representation. The validity and reliability of estimates of VO2max are compromised when the participants being tested do not represent the sample of participants used to develop the test. (p. 110)

This becomes a troubling factor when the tests are meant to be used in a diverse ethnic population but were developed using a population group that was not diverse. Vehrs and Fellingham (2006, p. 109) found that both the ARCET and YMCA CE test significantly overestimated ($p < .0001$) VO_{2max} values in the African-American male participants but did not see the same overestimation in the white participants. They also state that researchers and exercise professionals often overlook these ethnic differences because at the time of writing there was not a lot of strong evidence to confirm that these differences in ethnicity made any difference (2006, p. 110). It has been established that there is a significant difference in the resting heart rates (RHR) of African-American (AA) and white men and women prior to the age of 35 (Persky, Dyer, Stamler, Shekelle, & Schoenberger, 1979). Persky et al. (1979) noted that some possibilities for this significant difference in RHR were greater physical fitness in AA men in the sample population, or increased peripheral resistance in a larger percentage of young AA men than white men. The researchers did mention that there was no data or testing that was able to confirm or deny these hypotheses. This difference in resting heart rate was also shown to be independent of variables such as smoking, and adjustments for plasma glucose, serum cholesterol, relative weight, and systolic blood pressure. This information supported the conclusion of the researchers that the racial difference in heart rate was due to factors involved

in ethnic differences (1979, p. 279). The results from Persky et al. (1979) are important for the Vehrs and Fellingham study because they show that heart rate, which is one of the two primary components of a submaximal cycle ergometry test, is already substantially different at rest in white and black males in their sample population. Berry, Zehnder, Berry, Davis, & Anderson (1993) took this a step further and found that AA males not only had a lower RHR, but also a lower exercise heart rate (EHR) as well. The data from the Berry et al. (1993) study reported AA vs white male EHR, respectively, as: 99±1 and 107±1 at 0 watts(W), 108±1 and 114±1 at 50 watts(W), and 119±1 and 127±1 at 100 watts(W). Some explanations for the lower RHR and EHR in the AA population include a lower number of beta receptors, less sensitive beta receptors, and a higher total blood volume (although this appears to be refuted in the literature). Berry et al. described a possible trend towards a higher stroke volume being a mechanic that can explain the lower heart rates found in AA males when compared to their Caucasian counterparts who match their cardiac output with a higher heart rate (1993). This research demonstrates that both the ARCET and YMCA CE test are both poor predictors for the aerobic capacity of AA males in particular, as this population was not used in the original development of the protocols. With this information, caution should be taken when using either bike protocol on an ethnic group that was not part of the original development process.

Although there has been an abundant amount of research over the years attempting to validate the submaximal ARCET and YMCA CE test against a VO_{2max} test, there are very few studies directly comparing the two protocols to each other. However, there are examples in the literature of the ARCET or YMCA CE test being compared to other submaximal tests in terms of predictive accuracy. One example is in a study from by VanderVeen (2018) who selected six

females and thirteen males to participate in three submaximal exercise tests to determine which of three submaximal exercise tests using a variety of modalities were the most accurate in predicting VO_{2max}. The three submaximal tests that were chosen for this study were the ARCET, the Queens College step test, and the Rockport 1-mile walk test (VanderVeen, 2018). The author noted that there are other submaximal tests that could have been included, but the goal was to compare three tests that involved three different modalities. VanderVeen concluded that the "Rockport 1-mile walk may be the preferred method for absolute VO_{2max}" (2018, p.33). Absolute VO_{2max} is just a statement of an obtained value while relative VO_{2max} takes body weight into account in an attempt to normalize the data outside of an individual's weight. The Rockport test had the lowest standard estimate of error (SEE), which is a statistical test used to measure the accuracy of predictions, as well as the highest correlation factor. The Rockport, ARCET, and the Queens College step test resulted in SEE ,(and correlation) values of ±0.41 $L \cdot min^{-1}$,(0.78); ±0.46 $L \cdot min^{-1}$, (0.68); and ±0.66 $L \cdot min^{-1}$ (0.59) respectively. Each of these tests were statistically compared to the treadmill Bruce protocol as the VO_{2max} test. Although the Rockport test was concluded to be the most accurate submaximal test to predict absolute VO_{2max} values, VanderVeen still found that "it is difficult to argue that one of the submaximal tests used in this study is preferred over another for predicting relative VO2max" (2018, p. 33). Unfortunately, there appears to be no research that compares the YMCA CE test with either the Rockport 1-mile walk test or the Queens College step test.

In 2004, Wendy E. Davis wrote her master's thesis on comparing the ARCET and the YMCA Ce test to a cycle ergometer VO_{2max} test. Research directly comparing these two submaximal tests to each other, and how they perform compared to a VO_{2max} test, had not been previously

conducted. For the study, Davis selected a sample population of twenty-three college students (11 males and 12 females). All twenty-three participants had to perform all three tests: submaximal ARCET, submaximal YMCA CE test, and a VO_{2max} cycle ergometer test. The data that was reported showed oxygen consumption values of 42.87 ± 9.90 $mL \bullet kg^{-1} \bullet min^{-1}$, 46.09 ± 13.18 $mL \bullet kg^{-1} \bullet min^{-1}$, 46.18 ± 8.84 $mL \bullet kg^{-1} \bullet min^{-1}$ for the VO_{2max}, YMCA CE test, and the ARCET, respectively (Davis, 2004). The correlation coefficient was highest between the VO_{2max} test and the YMCA CE protocol (.83), and lowest between the VO_{2max} test and the ARCET (.55). The correlation coefficient between the YMCA CE test and the ARCET was in-between at .73. Davis (2004) compares her correlation coefficient of .55 between ARCET and the VO_{2max} to those in Siconolfi et al. (1982) and Terry, Tolson, Johnson, & Jessup (1977) who found values of .82 and .65, respectively. For the YMCA CE test, Beekley et al. (2004) found a .77 correlation coefficient to a treadmill VO_{2max} test, and Garatachea et al. (2007) found a .68 and .73 correlation coefficient for males and females, respectively. Both of these values were lower than the .83 correlation found by Davis (2004) for the YMCA CE test. The conclusion of Davis's study showed that both the ARCET and YMCA CE test are both valid predictors of VO_{2max} in individuals, but YMCA was a more accurate protocol for prediction of maximal oxygen consumption from a submaximal test.

Conclusion

The current research shows that both the YMCA CE test and ARCET can be used to predict the maximal oxygen consumption of an individual using a submaximal test instead of a full-exertion maximal test. This is a major benefit to the health and fitness community because it allows the measurement of VO_{2max} values in people that would otherwise be unable to reach

a maximal level of exertion due to a wide range of medical conditions or being in a deconditioned state. Neither submaximal test will result in a 1.0 correlation coefficient, but they produce results that are statistically significant to the maximal tests (Davis, 2004).

The previously stated question that was to be answered by this literature review was as follows: Will the decision made by an exercise professional to choose to use one test over another have any impact, and is one test better for a certain population over another? The current literature shows that an exercise professional can safely choose either the ARCET or YMCA CE test without being concerned that either one will produce an inaccurate result, assuming the test was performed correctly. However, the one direct comparison between the tests that was found showed that the YMCA CE test had a higher correlation coefficient to the maximal test than the ARCET did (Davis, 2004). This area of research that involves directly comparing the two protocols needs to be studied many more times to ensure that these results can be repeated multiple times. In future studies, the population that is used should be changed as well. Many studies that involve maximal-exertion cardiac testing use younger populations because they are more likely to complete a full VO_{2max} test.

The subject of population was the second piece of the question that this literature review intended to answer. According to the current literature, this is one of the primary problem areas that the protocols have. The ARCET was developed in the 1950's and the YMCA CE test was published in 1989. Some of the studies that involve these tests mention that neither one may have had a very diverse participant population during development. This leads to skewed results when testing on individuals that are not a part of the ethnic group involved in creating the test. This was shown to be the case in the study from Vehrs and Fellingham in 2006 as both tests

overestimated the VO_{2max} values of AA participants. Future research needs to be done that creates protocols designed around either encompassing a more diverse range of ethnicities or created for specific ethnic groups so that they can obtain more accurate data. Persky et al. (1979) reported resting heart rates as being different in AA men when compared to white men. Since this difference may also be true in other non-white populations, more research needs to be done to see if it has any impact on aerobic capacity.

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