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Determining cardiovascular fitness normative reference values in a university aged Canadian population using maximal exercise testing

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Abstract

Study aim: Maximal oxygen uptake (VO_{2max}) is the greatest rate at which the body can use oxygen and is an indicator of aerobic power. Although aerobic fitness is such a valuable determinant of health, there is limited research with established normative values for a healthy young adult Canadian population. The purpose of the study was to develop normative reference values for a Canadian young-adult population.
Material and methods: 550 undergraduate student (280 male and 270 female) participants, with a mean body mass (BM) of 72.08 ± 15.05 kg, mean age of 21.16 ± 1.26 years old and mean height of 171.95 ± 10.25 cm completed a VO_{2max} test using the Bruce treadmill protocol. Male and female classifications were established for the total exercise time in minutes and for the measured VO_{2max} using percentiles and a seven-category classification system.
Results: There were statistically significant differences between the sexes for VO_{2max} values ($p < 0.001$). The measured assessment for the healthy young Canadian adults showed a mean VO_{2max} value of 40.90 ± 7.50 mL/kg/min for females and 49.89 ± 9.20 mL/kg/min for males. Females were able to withstand the exercise protocol for a mean of 11.92 ± 1.97 minutes, while males exercised for an average of 14.33 ± 2.40 minutes before the test was terminated.
Conclusions: This study provides specific normative values for the aerobic fitness of a university aged Canadian population which can be used as reference values for cardiovascular health and fitness assessments.

Keywords: VO_{2max} testing – Aerobic capacity – Graded exercise test – Bruce protocol

Introduction

Maximal oxygen uptake (herein: VO_{2max}) is the greatest rate at which the body can use oxygen, and is the point where an increase in oxygen uptake is not seen with a corresponding increase in workload [5, 8, 12]. VO_{2max} provides an indication of aerobic power, which is an important component of health-related physical fitness, as it is closely related to heart function (since VO_{2max} is the product of maximal cardiac output and the arterial-venous difference) [5]. If a participant has a low VO_{2max} value, then they will be less able to produce energy via aerobic means, which may then be associated with the development of cardiovascular disease risk factors [7, 10, 11, 23]. VO_{2max} can provide a good indication of a person's health status and also allow the monitoring of progress in a fitness program [5, 11]. Accurate and reliable measurement of maximal aerobic fitness is therefore essential for determining health status.

Although aerobic fitness is such a valuable determinant of health, there is limited research with established normative values for a healthy young adult Canadian population. The aerobic power research has primarily focused on very specialized populations who were more active than the general population – including police officers, cross country runners, swimmers, speed skaters, rowers, squash players and triathletes [21, 30]. In addition, many researchers have focused on the normative profiles of children from countries other than Canada [1, 5, 17, 18, 28, 29, 32]. VO_{2max} studies have often been based on small sample sizes which do not allow for comprehensive normative data profiles to be created [9, 21, 38]; while other researchers only presented mean values rather than percentiles and classification schemes [14, 17, 27, 36]. This lack of reference values in the literature may limit a clinician's ability to interpret VO_{2max} data.

Since maximal values are affected by several factors [11], it is important to define the population when creating normative reference values. VO_{2max} values have been

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found to be lower in women [6, 7, 14, 17, 26, 27, 31], vary inversely with age [3, 24] and vary directly with height [11], body surface area [11], and body weight [11, 24], and change based on training state [5, 11, 24, 34]. Therefore, the purpose of the study was to develop normative reference values and a classification system for a university aged Canadian young-adult population.

Materials and methods

Experimental approach to the problem

The study design was chosen to examine both sexes over a ten-year period to enable a large cohort of young healthy adults to be evaluated. Dependent variables included both the measured VO_{2max} values and the total exercise time for the participants to achieve their VO_{2max}, since total exercise time is often used to estimate $VO_{2max.}$

Subjects

A convenience sample was used in this study, since the inclusion criterion was being enrolled in a physiology laboratory course at a Canadian University. A total of 605 participants completed the study, and 550 participants with complete data sets were included for analysis (see exclusions described below in Statistical Analysis). All volunteers completed a VO_{2max} test using the Bruce treadmill protocol. Participants consisted of individuals with varying levels of athletic ability and fitness status (although not specifically assessed), who, prior to testing, completed the Get Active Questionnaire [2] or Physical Activity Readiness Questionnaire [35] and signed institutionally cleared Research Ethics Board consent forms after being informed of the benefits and risks of participating in the study.

Following exclusions, the study consisted of 280 male (50.09%) and 270 female (49.91%) participants, with a mean body mass (BM) of 72.08 ± 15.05 kg (80.90 kg males, 62.94 kg females), mean age of 21.16 ± 1.26 years old (21.31 years males, 20.00 years females) and mean height of 171.95 ± 10.25 cm (178.97 cm males, 164.67cm females).

Procedures

VO_{2max} measurements were collected using computerized instrumentation with metabolic and respiratory equipment (COSMED Quark CPET Cardio-Pulmonary Exercise Testing with associated Software). Exercise testing was completed on a Trackmaster Treadmill using the Bruce Maximal Treadmill Protocol, which consisted of seven stages, each with a duration of three minutes. Speed and grade increased from stages one through seven (1.7mph/10%, 2.5mph/12%, 3.4mph/14%, 4.2mph/16%, 5.0mph/18%, 5.5mph/20%, 6.0mph/22%). Prior to testing, participants weight (in kg) and height (in cm) were obtained using a digital scale and stadiometer (Model 130500KL). Participant name, sex, height, weight, date of birth were inputted into the COSMED CPET system. The participant was fitted with the HR monitoring device, mask and headpiece compatible with the system, and an overhead harness for safety. A warm-up consisted of 3 minutes of walking at 1.7 mph and 0% grade; after which, the participant was verbally instructed not to hold onto the treadmill bars at any point during the test and were verbally encouraged to continue exercising as the workload increased. The test was terminated when the participant could no longer continue or if several of the subjective [e.g., rating of perceived exertion (RPE) between 17–20, appearance of exhaustion] and objective [e.g., respiratory exchange ratio of ≥1.1–1.15, achievement of age-predicted heart rate $(HR)_{max}$ or within 10 beats per minute of HR_{max}, a plateau in HR despite an increase in workload and a plateau in VO_2 despite an increase in workload] indicators were met [20]. Following the termination of the test, subjects walked for a minimum of five minutes at a grade of 0% and self-selected speed to cool down. The total exercise time and VO_{2max} value was obtained from the CPET Wasserman Report to ensure standardization between subjects.

Statistical analyses

Before proceeding with data analysis, the database was screened for missing data and normality using a Shapiro-Wilk test. The distributions were shown to deviate from normality, and the appropriate non-parametric tests were used in analyses. Outliers identified in the raw data set were included in the statistical analyses, as long as they were not considered to be erroneous due to data entry error. Participant data were removed due to data entry error (n = 17), withdrawing consent from sharing their test scores (n = 36) and being non-representative age (n = 2, age 39 and 52).

Statistical analyses were completed using the IBM Statistical Package for the Social Sciences (SPSS) software (version 29). Descriptive statistics and an independent samples t-test (Mann-Whitney U) were conducted to compare the means and determine statistical significance ($p < 0.05$) between the sexes for each of the dependent variables (total exercise time in minutes and the measured VO_{2max}). Male and female classifications were established for the total exercise time in minutes and the measured CPET (COSMED) software VO_{2max} (mL/min/kg). To create performance classifications, the range for both the raw VO_{2max} data and their associated Z-scores were calculated using Microsoft Excel. The range was then divided by seven to generate seven classifications, a modification to the process utilized by Zupan et al. [39], and similar to that used by Duquette et al. [13]. Each classification was separated by equal raw data scores and Z-score increments.

For example, the Z-score range for female VO_{2max} values using the CPET software was 5.79 (–2.39 to 3.39), meaning that each of the seven performance classifications was separated by 0.83 SDs. This value corresponded to equal raw data score categories of 6.21 mL/kg/min (since the raw data score range of 43.50 mL/kg/min was divided by 7). For example, 6.21 mL/kg/min was subtracted from the highest VO_{2max} score recorded (66.41 mL/kg/min – 6.21 mL/kg/min) to yield an 'elite' classification of >60.20 mL/kg/min. Likewise, 6.21 mL/min/kg was subtracted from 60.20 mL/kg/min to yield an 'excellent' classification of 53.99 mL/kg/min – 60.20 mL/kg/min, and so on for the remainder of the classification categories. Male VO_{2max} values had a Z-score range of 6.55 (–3.00 to 3.54), therefore, each classification was separated by 0.94 SDs. This value corresponded to equal raw data score categories of 8.62 mL/kg/min (since the raw data score range of 60.36 mL/kg/min was divided by 7). For example, 8.62 mL/kg/min was subtracted from the highest VO_{2max} score recorded (82.58 mL/kg/min – 8.62 mL/kg/min) to yield an 'elite' classification of >73.96 mL/kg/min. Likewise, 8.62 mL/kg/min was subtracted from 73.96 mL/kg/min to yield an 'excellent' classification of 65.34 mL/kg/min – 73.96 mL/kg/min, and so on for the remainder of the classification categories. Performance classifications consisted of elite, excellent, above average, average, below average, fair, and poor, which is similar to the classification method used by Duquette et al. [13] and Zupan et al. (2009). The same procedure was utilized to create performance classifications for total exercise time in minutes.

Results

The Independent Samples Mann-Whitney U test revealed statistically significant differences between the sexes for VO_{2max} values ($p = 0.000$) with a mean VO_{2max} value of 40.90 ± 7.50 mL/kg/min for females and 49.89 ± 9.20 mL/kg/min for males. Females were able to withstand the exercise protocol for a mean of 11.92 ± 1.97 minutes, while males exercised for an average of 14.33 ± 2.40 minutes before the test was terminated. VO_{2max} means, standard deviations, maximum and minimum values are presented in Table 1. Female and male performance classifications (with seven categories ranging from poor to elite) may be found in Table 2. Percentile rankings ranging from 5^{th} to 95^{th} percentiles for male and female VO_{2max} data are presented in Table 3.

Discussion

The main objective of this study was to quantify cardiovascular fitness by producing classifications and percentiles that represent a healthy, young, adult Canadian. The study combats limitations of small sample sizes [9, 21, 38] and specific elite athletic populations [9, 21, 24, 27, 38] which was the main focus in previous maximal exercise tests. In this study, males produced higher relative mean VO_{2max} values compared to females across the measured CPET software. These findings support common relative VO_{2max} trends reported in the literature [7, 14, 17, 26, 27, 31]. The trend of VO_{2max} values being about 20% lower in females than in males can be linked to a combination of factors in females which include shorter height [22], smaller lungs [3], smaller heart sizes and lower hemoglobin mass, which limits the capacity to deliver oxygen to skeletal muscle [25].

The present study's population had mean VO_{2max} values of 40.90 ± 7.50 mL/kg/min for females and 49.89 ± 9.20 mL/kg/min for males. These are very similar to cardiovascular fitness results reported on males and females, of 40.30 ± 7.10 mL/kg/min and 48.60 ± 9.60 mL/kg/min, respectively – a similarity which may have resulted from the same age group (20–29 years of age) being examined in both studies [14]. In a study using a population consisting of Brazil students aged 14 – 19 years old, mean VO_{2max} values were reported to be 35.33± 3.66 mL/kg/min for females and 42.68 ± 5.34 mL/kg/min for males [17], both much lower than the present study results. This could be explained by the younger age group and/or that the majority of individuals had low physical activity levels [17].

Table 1. Measured maximal oxygen uptake values and Total Exercise Time for Healthy Young Canadian Adults VO_{2max}

VO_{2max} method of assessment	Sex	N	Mean	Std. Deviation	Minimum	Maximum
	Males	280	49.89	9.20	22.22	82.58
CPET software [mL/kg/min]	Females	270	40.90	7.50	22.91	66.41
	Total	550	45.48	9.53	22.22	82.58
	Males	280	14.33	2.40	7.48	21.23
Total exercise time [min]	Females	270	11.92	1.97	6.55	19.15
	Total	550	12.96	2.51	6.55	21.23

Calculations were made rounding to the closest two decimal places. CPET = Cardio-Pulmonary Exercise Testing.

Table 2. VO_{2max} percentile rankings for females and males

	Females (20–29 years old)		Males (20–29 years old)	
Percentiles	VO_{2max} [mL/min/kg]	Total exercise time [min]	VO_{2max} [mL/kg/min]	Total exercise time [min]
5	28.05	9.11	34.95	10.55
10	31.85	9.80	38.61	11.58
15	33.26	10.07	41.45	12.12
20	33.80	10.35	43.28	12.48
25	35.62	10.56	44.71	12.67
30	37.33	10.82	45.74	12.88
35	38.45	11.05	46.91	13.27
40	39.04	11.17	47.72	13.57
45	39.77	11.34	48.26	13.98
50	40.34	11.58	49.28	14.41
55	41.05	11.97	50.10	14.71
60	42.34	12.21	51.21	15.10
65	43.50	12.65	52.26	15.24
70	44.57	12.83	53.47	15.39
75	45.54	13.12	54.75	15.78
80	46.89	13.52	56.01	15.98
85	48.88	13.96	58.09	16.41
90	50.70	14.44	60.70	17.09
95	54.16	15.40	66.04	18.97

Percentile rankings were calculated by rounding to the closest two decimal places.

Table 3. VO_{2max} classifications for females and males

	Females (20–29 years old)		Males (20–29 years old)	
Classifications	VO_{2max} [mL/kg/min]	Total exercise time [min]	VO_{2max} [mL/kg/min]	Total exercise time [min]
Elite	>60.20	>17.35	>73.96	>19.27
Excellent	53.99–60.20	15.55–17.35	65.34–73.96	17.31–19.27
Above average	47.78–53.98	13.75–15.54	56.72–65.33	15.35–17.30
Average	41.57–47.78	11.95–13.74	48.1–56.71	13.39–15.34
Below average	35.36–41.56	10.15–11.94	39.48–48.09	11.43–13.38
Fair	29.15–35.35	8.35–10.14	30.86–39.47	9.47–11.42
Poor	<29.15	<8.35	<30.86	<9.47

Classifications were calculated by rounding to the closest two decimal places.

In contrast, many studies have assessed cardiovascular fitness of athletes who participated in a variety of different sports including badminton, rowing, running, squash, and triathlons [27]. Unsurprisingly, the long-distance runners were shown to have much greater mean VO_{2max} values [61.40 ± 4.60 mL/kg/min for females and 77.40 ± 3.70 mL/kg/min for males] [27] when compared to the present study.

Although fitness status was not specifically assessed prior to the study, kinesiology students have been shown to be more aware of physical activity guidelines when compared to students studying other disciplines [37]. Another study, evaluating cardiovascular fitness among kinesiology students aged 20.9 ± 1.8 years of age, found that females had a mean VO_{2max} value of 42.8 ± 11.3 mL/kg/min while males had a mean VO_{2max} value of 51.8 ± 13.1 mL/kg/min [4]. These slightly higher VO_{2max} values have to be interpreted with caution, due to the smaller sample size used in that study (n = 14).

Prior to the current study, normative reference values in the literature primarily focused on youth [18, 28, 32], used submaximal values to predict VO_{2max} [15] or used methods other than a graded treadmill exercise test; including cycle ergometry [6], a multistage 20-m running test [19, 29] or a step test [33]. Percentile rankings created based on the present Canadian adult population designated the 50th percentile for measured VO_{2max} to be 40.34 mL/kg/min for females and 49.28 mL/kg/min for males. Aerobic fitness normative reference values have been created for a large, multiethnic, nationally representative sample of U.S. adolescents, aged 12–18 years old [15]. VO_{2max} was predicted using a graded treadmill exercise test and extrapolated heart rate data where VO_{2max} at the 50th percentile for females and males was found to be 37.4 mL/kg/min and 46.5 mL/kg/min, respectively [15]. These lower values may be attributed to a combination of factors including the use of a submaximal protocol [36], differences in Canadian and American fitness levels [16], the population potentially being less physically trained [5, 11, 24, 34] or age differences [15].

Normative-reference values for health-related physical fitness tests in first-year police officers have been predicted with the determination of VO_{2max} using a regression equation from a 2.4-km run time. In comparing the 60th percentile of participants (since only 20th, 40th, 60th and 80th were reported) that were 21 years of age, females and males had VO_{2max} values of 43 mL/kg/min and 51 mL/kg/min, respectively [30]; very similar to the present study which had 60th percentiles of 42.34 mL/kg/min for females and 51.24 mL/kg/min for males. Future research is needed to see if these similarities would still exist if police officers were to perform a maximal graded exercise test collecting expired gases from a metabolic cart. Smaller intervals of percentiles (i.e., every 5th or 10th percentile) are also needed to assess differences across the lower and higher classifications. In addition to percentiles, classification categories can be a useful tool in assessing cardiorespiratory fitness, especially when comparing large populations. Normative VO_{2max} data for an Indian population who were 18–25 years old had been presented with a six-category classification system (very poor, poor, fair, good excellent and superior) [7]; a difference from the seven category classification system used in the present study. Excellent categories in the Indian population were found to be 37.0–41.0 mL/kg/min and 46.5 – 52.4 mL/kg/min for females and males, respectively [7]. These values are much lower than the present study, which determined the excellent category for females and males to be 53.99 – 60.20 mL/kg/min and 65.34–73.96 mL/kg/min, respectively. Differences may be explained through the population variances in body size, lifestyle, diet and physical activity levels; all factors which can influence maximal oxygen consumption [7]. Additionally, their exclusion criteria were students who regularly practice physical activity [7], whereas the present study included students of all activity levels, which may have contributed to obtaining a higher VO_{2max} [5, 11, 24, 34].

A limitation of this study was that fitness was not directly quantified. As kinesiology students have been shown to be more aware of fitness and health guidelines [37], they *may* also be more active than age – and sex-matched peers, even though a wide-variety of physical activity levels were tested (i.e., from sedentary students to varsity athletes). Future research should directly quantify physical activity to glean a better understanding of fitness when creating future normative reference standards. In addition, ethnicity, diet and family medical history should also be assessed, since these factors may impact cardiovascular fitness.

This study's main purpose was to create normative-reference values, classifications, and percentile rankings for a healthy, young Canadian adult population that can be used during a maximal oxygen uptake test, which is a useful and accurate method of assessing cardiovascular fitness and aerobic power [8, 26]. As cardiorespiratory fitness has been shown to decrease across the lifespan from a physiological standpoint [3, 24] the need for age-based reference values remains of utmost importance. Results can provide a practitioner and/or clinician with baseline values to address health, which can be used to monitor the effects of physical activity interventions. Moreover, these values can translate to realistic guidelines and goals for patients, as results may show indicators for health risks such as cardiovascular disease [7, 10, 11]. Creating classifications allow for practitioners to evaluate results at both the individual and population level. As higher categories and percentiles can have positive effects on physical and mental health, results can indicate a need to make a lifestyle change [26].

Conflict of interest: Authors state no conflict of interest.

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