

## Evaluation of maximal $O_2$ uptake with undergraduate students at the University of La Reunion

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**Tarnus E, Catan A, Verkindt C, Bourdon E.** Evaluation of maximal  $O_2$  uptake with undergraduate students at the University of La Reunion. *Adv Physiol Educ* 35: 76–81, 2011; doi:10.1152/advan.00042.2010.—The maximal rate of  $O_2$  consumption ( $\dot{V}O_{2max}$ ) constitutes one of the oldest fitness indexes established for the measure of cardiorespiratory fitness and aerobic performance. Procedures have been developed in which  $\dot{V}O_{2max}$  is estimated from physiological responses during submaximal exercise. Generally,  $\dot{V}O_{2max}$  is estimated using the classical renowned Astrand-Ryhming test. In young adults, poor fitness and low aerobic performance are often associated with a sedentary lifestyle, which is a well-described factor for the development of obesity and its related disorders such as cardiovascular diseases and type 2 diabetes. In the Indian Ocean, the inhabitants of La Reunion Island, a French overseas department, exhibit an increasing prevalence of obesity and type 2 diabetes. At the University of La Reunion, a new laboratory course involving students was designed to teach the indirect evaluation of their  $\dot{V}O_{2max}$  from the classical Astrand-Ryhming test and using a cycle ergometer as the exercise mode. Inverse and significant correlations were established between the students' fat mass percentages and their  $\dot{V}O_{2max}$  and between their waist-to-hip ratio and  $\dot{V}O_{2max}$  as well. Results from the international physical activity questionnaire showed that most participants in this laboratory were sedentary students. Therefore, this laboratory makes the students practice and understand the use of a classical test to estimate their  $\dot{V}O_{2max}$ . It also alerts them to the correlation between a sedentary lifestyle and higher body fat content. This exercise allowed students to use a scientific method to engage the problem of sedentary lifestyle, which is a real world issue.

obesity; fat mass

THE ABILITY to consume  $O_2$  ultimately determines any human's or animal's capacity for cardiorespiratory endurance. The maximal rate of  $O_2$  consumption ( $\dot{V}O_{2max}$ ) constitutes one of the oldest fitness indexes established for the measure of cardiorespiratory fitness and aerobic performance (6). During aerobic activity, there are well-known linear relationships between heart rate (HR) and  $O_2$  consumption ( $\dot{V}O_2$ ). The increase of  $\dot{V}O_2$  is related to the  $O_2$  demand of working muscles and is marked by the linear relationship between  $\dot{V}O_2$  and the work rate.  $\dot{V}O_{2max}$  is the highest rate of  $\dot{V}O_2$  attainable during maximal and exhaustive exercise. For each individual, this value is reached when the maximum HR is reached. Thus, by measuring HR at different intensities of exercise for a partic-

ular activity and by knowing the theoretical maximum HR,  $\dot{V}O_{2max}$  can be estimated. As a consequence, procedures have been developed in which  $\dot{V}O_{2max}$  is estimated from physiological responses during submaximal exercise. Generally,  $\dot{V}O_{2max}$  is estimated using the classical renowned Astrand-Ryhming test (2, 3, 7). Three major factors determine  $\dot{V}O_2$  values: cardiac output determined by the ejection rate of blood by the heart in 1 min (stroke volume  $\times$  HR), the amount of hemoglobin in red blood cells, and the mass of exercising skeletal muscle and its ability to use  $O_2$ .

$\dot{V}O_2$  can be calculated by the Fick equation as follows:  $\dot{V}O_2 = Q_c \times (a-v)O_2$ . This equation expresses the relationship among  $\dot{V}O_2$ , cardiac output ( $Q_c$ ), and the arteriovenous  $O_2$  difference [(a-v) $O_2$ ].

In young adults, poor fitness and low aerobic performance are often associated with a sedentary lifestyle, which is a well-described factor for the development of obesity and its related disorders such as cardiovascular diseases and type 2 diabetes. In the Indian ocean, the inhabitants of La Reunion Island, a French overseas department, exhibit an increasing prevalence of obesity and type 2 diabetes (4). Today, up to 20% of the adult population is diabetic and ~50% is overweight or obese. Furthermore, the onset of type 2 diabetes occurs at 45 versus 50 yr of age in mainland France, with an increase in the comorbidities. Because of a drastic change in the way of life from traditional habits to that of a Western type over just a few decades (4), La Reunion is facing a dramatic public health issue. With 37% of the population being under 20 yr old, efforts are needed to provide a health awareness program for young people.

At the University of La Reunion, efforts are made to develop laboratories in physiology where students not only practice and understand physiological concepts but also investigate and face the influence of their lifestyle (excessive sugar consumption, sedentary, fat content, etc.) on the physiology of their body and on their health. Recently, we designed a laboratory to teach undergraduate students in physiology the use of anthropometric measurements for the estimation of their body composition (9). In addition, we reported another laboratory where students study their glycemic response after food intake (10).

Despite the numerous scientific publications reporting physiological or pathological condition influences on  $\dot{V}O_{2max}$  values, no protocol for  $\dot{V}O_{2max}$  evaluation for students and teachers has been published in *Advances in Physiology Education*. In the present laboratory, students evaluate their  $\dot{V}O_{2max}$  from the classical Astrand-Ryhming test and using an ergometry cycle as the exercise mode. Students performed statistical

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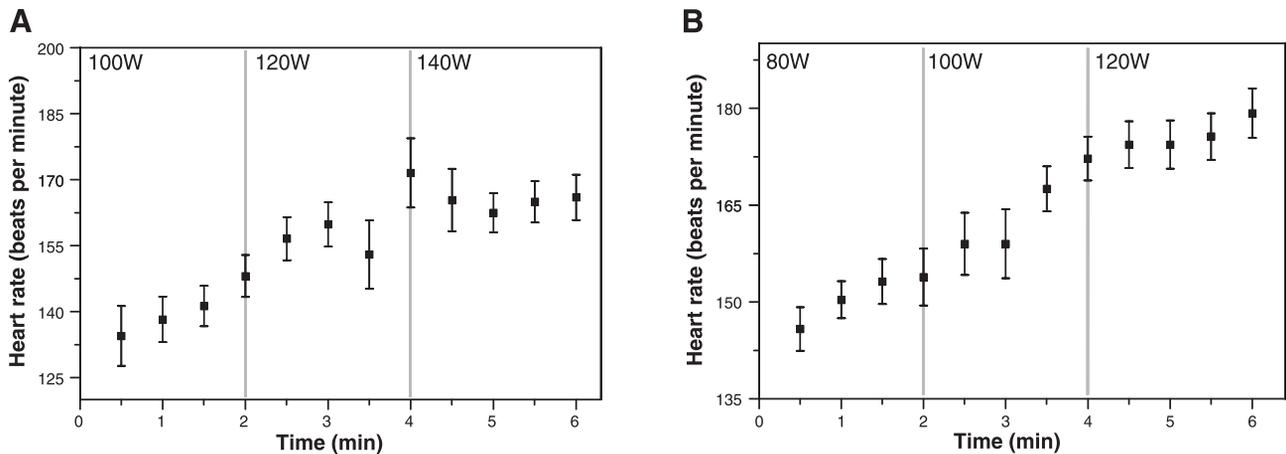


Fig. 1. Recordings over time in the different intensity steps of student's heart rates (HRs). Four heart cardiac frequency measurements were performed for each step of exercise intensity. *A*: HRs of men. *B*: HRs of women. Each point is the mean  $\pm$  SE of values obtained by students who participated in the test ( $n = 4-8$  subjects in *A* and 17-32 subjects in *B*).

analysis of the data obtained to relate  $\dot{V}O_{2\max}$  to their body composition and to their weekly physical activity. This exercise allowed them to use scientific methods to engage a real world issue.

## METHODS

### Participants

Students in this laboratory were in their fourth semester preparing for a Bachelor's degree in Biology at the University of La Réunion. During this year of study, they had 42 h of lectures on cardiovascular and digestive physiology in addition to 6 h of classroom exercises related to their laboratory activities. They also had to participate in four 3-h-long laboratory courses in physiology. All students signed a consent agreement allowing the use of their anonymous data for publication in *Advances in Physiology Education*, and the laboratory activity was approved by the Institutional Review Board.

Students in the class ranged in age from 18 to 24 yr old. La Reunion's population is composed of multiple ethnic groups. Malabars or Tamil of Indian origin represent 25% of the island's inhabitants. About 35% of the population is of African/Malagasy origin. White Europeans make up ~25% of the population. The remaining 15% of the population is composed of Métis, Vietnamese, and

Chinese people. About same percentages were carried over in the classroom.

### Physical Activity Determination Using the International Physical Activity Questionnaire

One month before the session, students were given a questionnaire to determine their weekly physical activity. This questionnaire was adapted from the short version of the International Physical Activity Questionnaire (IPAQ), which allows determination of the activities done at work, as part of house and yard work, commuting, and in spare time for recreation, exercise, or sport. Information on the availability of IPAQ in different languages can be obtained at [www.ipaq.ki.se](http://www.ipaq.ki.se). Each student was asked to write down the estimated time spent doing moderate activity (such as walking) or vigorous activity (such as running or heavy lifting). Determination of total weekly physical activity was done according to IPAQ methods. In the RESULTS AND DISCUSSION, physical activity is expressed as metabolic equivalent threshold (MET)  $\cdot$  min  $\cdot$  wk<sup>-1</sup>. MET is defined as the ratio of metabolic rate (and therefore the rate of energy consumption) during a specific physical activity to the reference of metabolic resting rate (1 kcal  $\cdot$  kg<sup>-1</sup>  $\cdot$  h<sup>-1</sup>). By convention, 1 MET is considered as the resting metabolic rate obtained during quiet sitting. MET values of physical activities range from 0.9 (sleeping) to 18 (running at 17.5 km/h) (1).

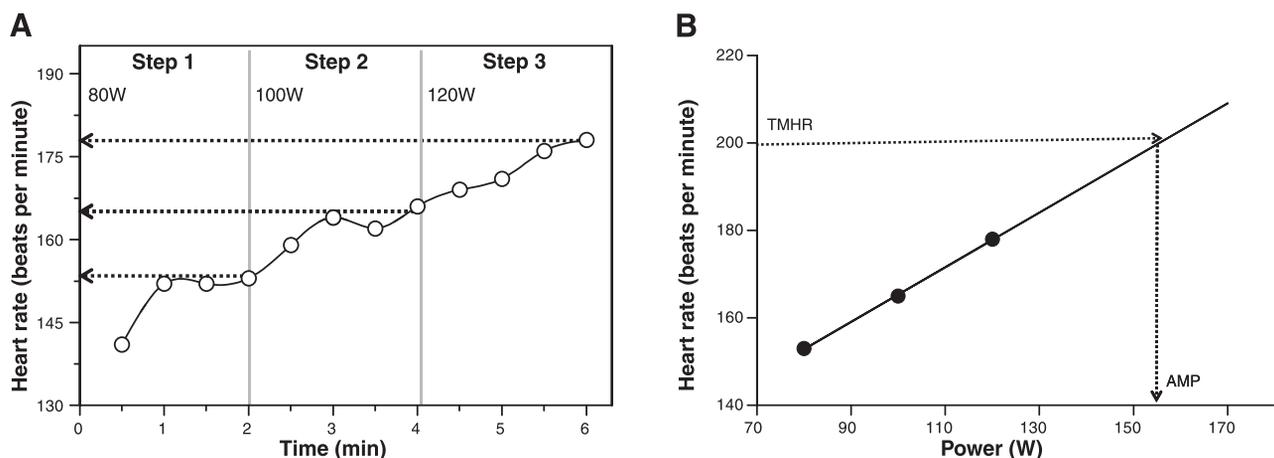


Fig. 2. Example of aerobic maximal power (AMP) determination for a 21-yr-old female volunteer. *A*: HRs for each power step are used to find the steady-state HR (dashed line). *B*: three steady-state HRs are plotted against the power intensity for each step. The points are connected by a best-fit line, which is extrapolated past the student's theoretical maximal HR (TMHR = 220 - 21 = 199). The x-axis value that corresponds to TMHR is the student's estimated AMP.

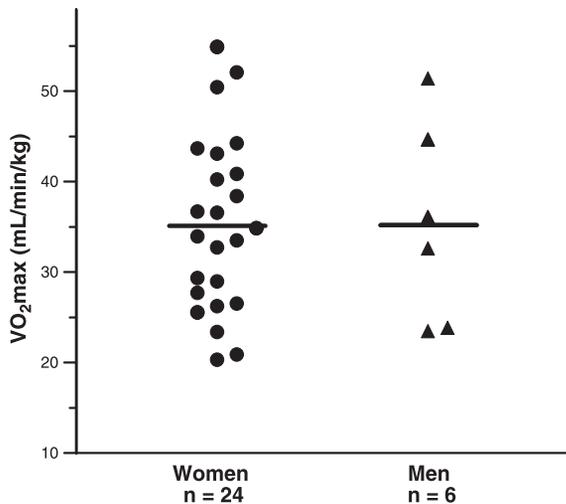


Fig. 3. Maximal O<sub>2</sub> uptake ( $\dot{V}O_{2max}$ ) values obtained by students.  $\dot{V}O_{2max}$  values evaluated by students from their evaluated AMP values are expressed in milliliters per minute per kilogram. Horizontal lines represent mean  $\dot{V}O_{2max}$  values for women and men.

A common classification for public health purposes is as follows:

- Light-intensity activities are defined as 1.1–2.9 METs.
- Moderate-intensity activities are defined as 3.0–5.9 METs.
- Vigorous-intensity activities are defined as 6.0 METs or more.

#### Prelaboratory Readings

One week before the session, students received a two-page document to acquaint them with the objectives and protocols of the laboratory and containing the informed consent.

#### Laboratory Procedures

The laboratory course started with an introduction to acquaint students with the objectives and methods of the exercise. This introduction is a 20-slide PowerPoint presentation in which links among physical activity, sedentary, lifestyle and health are also explained.

Volunteers were then asked to start the experience. In May 2009, when this laboratory was done for the first time at the University of La Reunion, 41 of 70 undergraduate students volunteered and performed the Astrand-Ryhming test. It should be noted that four students volunteered but could not performed the test due to elevated HR during the first power intensity (see *Data control and recording*).

Students were divided into working groups (2 or 3 students/group) containing at least one volunteer. Each student was given a two-page sheet on which students reported their results and interpretations.

#### Laboratory Data Sheet

**Principle.** This indirect method for  $\dot{V}O_{2max}$  estimation is based on a linear relation among HR, work rate, and  $\dot{V}O_2$ . By measuring HRs for three rates of work, it is possible to extrapolate the HR/power line to the theoretical maximal HR [TMHR = 220 – age (in yr)] and to read the theoretical aerobic maximal power (AMP) from the  $x$ -axis. From AMP, it is possible to predict  $\dot{V}O_{2max}$  using the following equation (2):  $\dot{V}O_{2max}$  (in  $ml \cdot min^{-1} \cdot kg^{-1}$ ) =  $[13.5 \times AMP$  (in W) + 100]/weight (in kg).

**Materials.** The following materials are needed for this test:

- Four ergometric cycles with electromagnetic braking (Ergocycle VM770; www.domyos.com)
- HR recorder (integrated in the ergocycle)
- Timer
- Pedaling cadency recorder (integrated in the ergocycle)

**Details about the test.** This test evaluates the power of exercise (braking strength). Three 2-min workloads are used.

- For men, the first, second, and third steps correspond to 100, 120, and 140 W, respectively.
- For women, the first, second, and third steps correspond to 80, 100, and 120 W, respectively.

**Protocol.** While performing the test, students should avoid speaking and should remain focused on the exercise. Students should pedal in a seated position and maintain a pedaling frequency between 60 and 80 rpm.

Before the test, there is a short warmup period of 2 min consisting of pedaling at a low power level (60 or 80 W for women or men, respectively). After this 2-min period, the test starts with the three 2-min steps of increasing intensities.

**Data control and recording.** During the test, the following parameters should be regularly checked:

- Power developed (in W), which should remain stable.
- HR, which should be recorded every 30 s.
- HR should never exceed 185 beats/min. If it does, the subject must end the test by slowing down the pedaling frequency over 2 min until coming to a complete stop.
- If HR is lower than 125 beats/min in *step 1*, a fourth step of higher intensity can be added. For men, this step would be 160 W; for women, step would be 140 W.

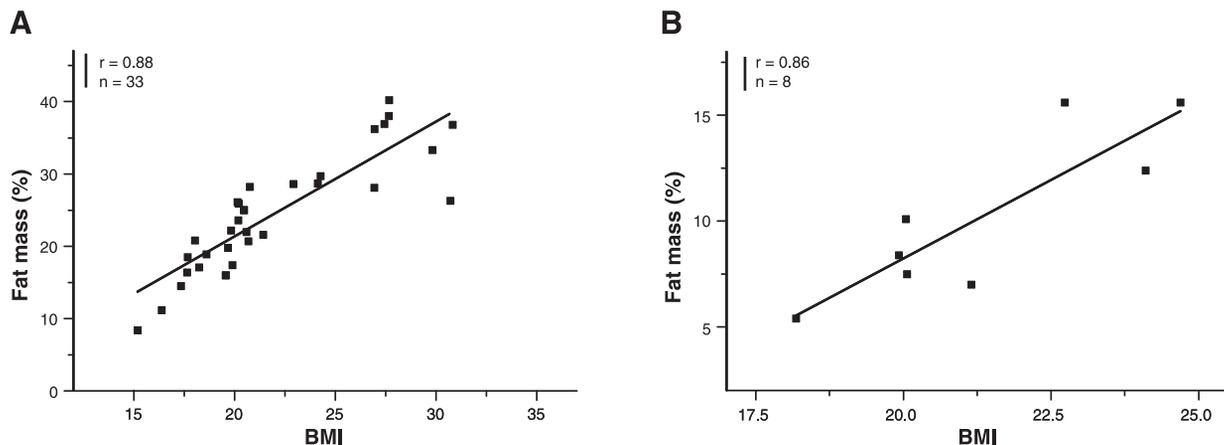


Fig. 4. Correlation between fat mass measured with a bioelectrical impedance and the body mass index (BMI). Fat mass percentages were determined using a bioelectrical impedance, and BMI (in  $kg/m^2$ ) was calculated as weight (in kg) divided by square height (in  $m^2$ ) in women (A) and in men (B).

*Additional information.* The data sheet also contained the following:

- Questions about the age and gender of the anonymous volunteer. The volunteers also indicated body mass index (BMI) values and fat mass percentages. The latter is determined through an impedance test during the laboratory class and using instructions from a previous practical course (9). Students are also asked to report their physical activity value in MET·min·wk<sup>-1</sup> estimated through the IPAQ (*Physical Activity Determination Using the IPAQ*).
- A table to be filled in with HR values (in beats/min). Four values (1 value measured every 30 s over 2 min) are obtained for each power step. If students perform three power steps, they report 12 values. A maximum of 16 values can be reported. It should be noted that  $\dot{V}O_{2max}$  could be evaluated with a minimum of two steps.
- A millimeter grid where students plot the variation curve of their cardiac frequency over time (see Fig. 2A). Students find a steady-state HR for each power step.
- A millimeter grid where students plot their steady-state HRs as a function of intensity (power) of the exercise. The three to four points are connected by a best-fit line, which is extrapolated past the student's TMHR [TMHR = 220 - age (in yr)]. The x-axis value that corresponds to the TMHR is the student's estimated AMP capacity. The estimated AMP is then inserted into the equation given above to estimate the student's  $\dot{V}O_{2max}$  (see Fig. 2B).

*Questions.* On the data report sheet, students had to answer the following eight other questions before they left the classroom:

1. What is your TMHR?
2. What is your estimated AMP?
3. What is your estimated  $\dot{V}O_{2max}$ ?
4. What is  $\dot{V}O_2$  and how does it vary after the increasing intensity of the exercise?
5. How does HR vary with increasing intensity of exercise?
6. Are you determining AMP directly or indirectly? If indirectly, how could you determine it directly?
7. Can you cite three factors that can influence  $\dot{V}O_{2max}$  values?
8. What are the four life activity domains in which you can be active?

*Typical student answers.* The following are examples of student comments regarding questions 6–8 of their data sheet report (see *Questions*):

- “During this laboratory, we indirectly estimate our maximal aerobic power (AMP) capacity for the evaluation of our  $\dot{V}O_{2max}$ . To determine directly AMP we should have used more sophisticated

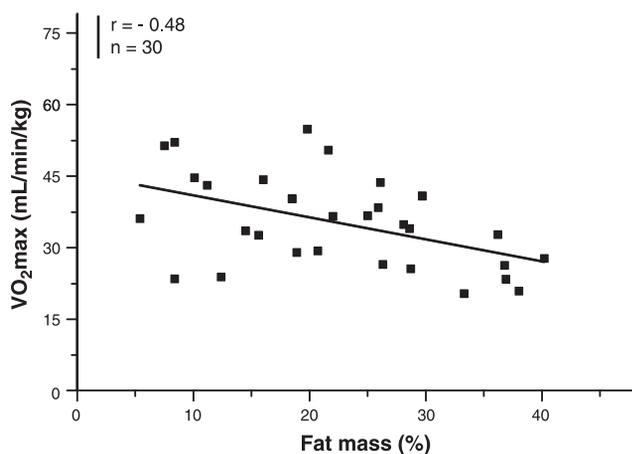


Fig. 5. Negative association between the evaluated  $\dot{V}O_{2max}$  with fat mass percentages.  $\dot{V}O_{2max}$  values were evaluated by students using the Astrand-Ryhming test as described in METHODS. Fat mass percentages were determined with a bioelectrical impedance.

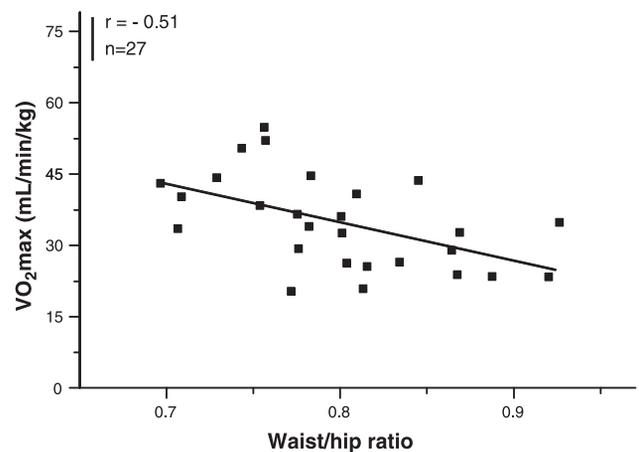


Fig. 6. Negative association between the evaluated  $\dot{V}O_{2max}$  and waist-to-hip ratio.  $\dot{V}O_{2max}$  values were evaluated by students using the Astrand-Ryhming test as described in METHODS. Waist and hip circumferences were measured using a measuring tape at the umbilici and at the widest buttock level, respectively.

apparatus, which directly analyzed the oxygen consumed during our breathing. In addition, we should have done a very intensive exercise reaching our maximal physical capacity.”

- “Among the different factors which can influence  $\dot{V}O_{2max}$  values are sex, age, sporting condition.”
- “The four life activity domains in which one can be active are leisure (if active in sports), work (depending of course on the job), commuting to school or work and at home (doing housework is a good way to be active at home).”

## RESULTS AND DISCUSSION

$\dot{V}O_{2max}$  was successfully evaluated by more than half of the students who participated in this laboratory. Using this protocol, even students who performed only two intensity steps of exercise could estimate their  $\dot{V}O_{2max}$ .

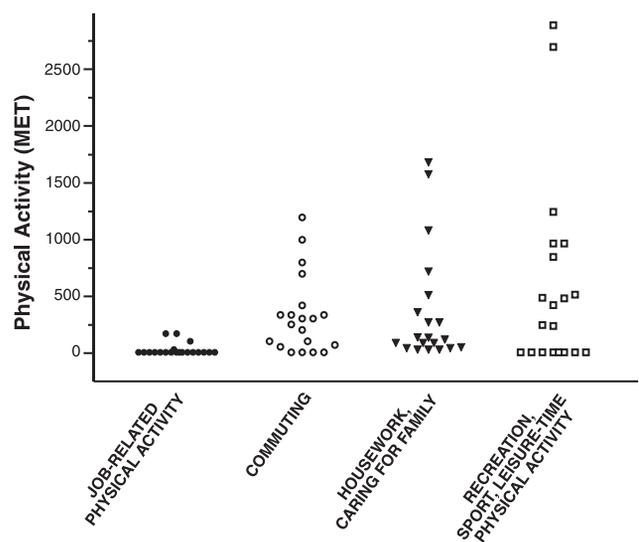


Fig. 7. Physical activity data from the International Physical Activity Questionnaire (IPAQ). Physical activities [expressed in metabolic equivalent of task (MET)] were obtained from 21 women who volunteered to the evaluation of their  $\dot{V}O_{2max}$ . In the IPAQ, physical activity is evaluated (in MET) in four categories of activity: job-related physical activity, transportation, housework, caring for family and recreation, and sport/leisure time physical activity.

They first experienced the relationship between HR and time in the different intensity steps (Fig. 1, A and B). Using the resulting relationship, students could extrapolate their AMP capacity, from which they predicted their  $\dot{V}O_{2max}$  using the formula explained above (see *Laboratory procedures*) (Fig. 2, A and B).

In our laboratory experimental conditions, the average  $\dot{V}O_{2max}$  values obtained by students (Fig. 3) were  $35.5 \pm 9.8$  ml·min<sup>-1</sup>·kg<sup>-1</sup> for women and men. There was a great heterogeneity of  $\dot{V}O_{2max}$  values, but they remain consistent with data found in the scientific literature for young persons (3, 5, 8). The association of BMI and obesity was demonstrated to the students by the establishment of a positive correlation between their obtained data of BMI and fat mass percentages (Fig. 4).

All participants' data showed negative correlations (Figs. 5 and 6) between  $\dot{V}O_{2max}$  and fat weight percentages or waist-to-hip ratios, a practical illustration of the association between fat composition or distribution and cardiorespiratory fitness and aerobic performance.

Analysis of students' total physical activity as self-reported from the IPAQ showed a wide heterogeneity, starting from 100 MET·min·wk<sup>-1</sup> (<10 min of walking/wk) to >3,000 MET·min·wk<sup>-1</sup> (>2 h of vigorous activity/wk). Figure 7 shows physical activity (in MET) of 21 students (women only) who answered the IPAQ. Most of them did not reach the recommended 30 min of moderate activity (3.0–5.9 METs), 5 times/wk, and could be considered as inactive. Very few of them practiced sports and showed a total physical activity superior to 1,000 MET·min·wk<sup>-1</sup>. For all students, maximum physical activity usually occurred during leisure time.

Finally, students'  $\dot{V}O_{2max}$  was compared with their self-reported total physical activity. In the laboratory conditions, no correlation was observed between these two parameters (not shown). This is probably due at least partially to the fact that most students in this laboratory had very low physical activity values from the IPAQ.

In addition, we noticed that 2 min for each step were sometimes not long enough to obtain a steady-state HR. This test at submaximal levels of exercise for the determination of AMP is based on the relationship between steady-state HR and the intensity of exercise at each stage (or step). If steady-state HR is not attained at each step during the test, the resulting relationship is not reliable. In our next laboratory, each step will be 3 min long to reach a better estimate of  $\dot{V}O_{2max}$  by the students.

Also, we noticed that due to the relatively sedentary lifestyle of our students, work rates have to be decreased for both women and men, because too many students were excluded due to high initial HRs. In our next laboratory, work rates for women and men will be set at 30-60-90 and 50-80-110 W, respectively.

It is important that students understand the indirect aspect of the evaluation of their  $\dot{V}O_{2max}$ . In this indirect evaluation, we can identify at least two different sources of error. On the one hand, the accuracy of the Astrand-Ryhming test in estimating maximal HR using  $220 - \text{age}$  (in yr) is subject to an error of +10 beats/min, which, in turn, introduces error into the estimation of AMP for each subject. In addition, difficulty in obtaining a steady-state HR within 2 min introduces error in the graph of steady-state HR as a function of power. For these

reasons, in other settings, the indirect evaluation of  $\dot{V}O_{2max}$  obtained from submaximal tests is mainly used to compare  $\dot{V}O_{2max}$  progression in individuals rather than to compare groups (smokers vs. nonsmokers or women vs. men, etc.).

### Conclusions

This laboratory course was conducted to allow students to evaluate their  $\dot{V}O_{2max}$ . During this session, students addressed the following three objectives:

During the laboratory, special emphasis was put on the strong link existing between obesity/sedentary lifestyle and metabolic syndrome. The two teachers involved in this class are also researchers working on the interaction between inflammation and adipocytes in type 2 diabetes/obesity pathophysiology, and they used recent scientific data to illustrate the link between type 2 diabetes/obesity and enhanced morbidity.

Students learned how to make accurate measurement using modern equipments. They learned how to indirectly evaluate their  $\dot{V}O_{2max}$  and gained an appreciation for the difference between an indirect and a direct measurement of a physiological parameter.

This exercise provided students with the opportunity to collect, graph, and evaluate data and interpret their results using a simple two-page report.

In addition to these three main objectives, this laboratory engages students in a real public health problem. Obesity is a dramatically increasing phenomenon and is associated with the occurrence of many pathologies. Our laboratory could make students sensitive to the influence of their lifestyle (BMI, fat content, etc.) on the physiology of their body and on their health.

Student reactions to this laboratory were very positive. All students participated very actively, even those who did not or could not volunteer for the Astrand-Ryhming test. More than half of the students volunteered to evaluate their own  $\dot{V}O_{2max}$ .

### ACKNOWLEDGMENTS

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### DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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