Assessing Maximal Oxygen Uptake: Creating Personalized Incremental Exercise Protocols Simply and Quickly

Carlo Ferri Marini, PhD,[1] Luca Correale, PhD,[2] Vittoria Carnevale Pellino, MSc,[2,3] Ario Federici,[1] Matteo Vandoni, PhD,[2,*] and Francesco Lucertini, PhD[1,*]
[1]Department of Biomolecular Sciences–Division of Exercise and Health Sciences, University of Urbino Carlo Bo, Urbino, Italy; [2]LAMA (Laboratory of Adapted Motor Activity), Department of Public Health, Experimental Medicine & Forensic Science, University of Pavia, Pavia, Italy; and [3]Industrial Engineering Department, University of Tor Vergata, Rome, Italy

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ABSTRACT

Measuring cardiorespiratory fitness (CF) is important for researchers, clinicians, and exercise practitioners to assess an individual's CF. One method of assessing CF is accomplished by measuring the maximal oxygen uptake during a personalized maximal graded exercise test (GXT). Tailoring a GXT protocol to a specific subject can be troublesome and time-consuming. In this article, simple and ready-to-use spreadsheets allowing the creation of individualized walking, running, and cycling GXT protocols are presented and explained. The procedures within the spreadsheets are based on the latest validated protocols, and the spreadsheets represent a time-saving, practical, and useful tool.

Address correspondence to Carlo Ferri Marini, carlo.ferrimarini@uniurb.it.
*Authors share senior authorship

INTRODUCTION

Cardiorespiratory fitness (CF) is positively associated with health status and inversely associated with the risk of cardiovascular disease and premature all-cause mortality (1,11,13,15). Measuring CF is of utmost importance for researchers, clinicians, and exercise practitioners to assess the physical fitness of their subjects, patients, or clients. Indeed, CF is not only an individual characteristic, but also a key consideration in prescribing an exercise training program and can also affect an individual's ability to adapt to such a program (13). Most exercise specialists and practitioners working at human performance laboratories, fitness centers, and research institutions have probably had to assess the CF levels of their subjects or clients.

Maximal oxygen uptake ($\dot{V}O_2max$) is considered one of the most valid indices of CF, and one of the most accurate methods to assess it is using indirect calorimetry during a maximal graded exercise test (GXT) (2). This method is used to estimate the energy produced by the body by measuring the ventilatory gases, namely the amount of oxygen consumed, and carbon dioxide produced by the body. The ventilatory gases are measured using highly sensitive devices called metabolic carts or metabolic measurement carts. These carts measure oxygen uptake and carbon dioxide production by collecting and measuring the amounts of oxygen and carbon dioxide that are expired and comparing those amounts to those which are inspired.

Exercise professionals can use several different GXT protocols to assess their clients' CF; however, using different GXT protocols can lead to different

KEY WORDS:
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CF measurements (8,16). Ramp protocols, characterized by smaller and more frequent work rate increments that are tailored to an individual's CF level, are superior to standardized protocols for assessing $\dot{V}O_2$max (8). Indeed, using ramp protocols makes it possible to achieve higher $\dot{V}O_2$max than standardized protocols (8). Moreover, tailored ramp protocols yield more uniform physiological adjustments to work rate increments, which improve the linearity between $\dot{V}O_2$ and work rate and facilitate the acquisition of information such as ventilatory threshold. Ramp protocols also allow us to avoid abrupt exercise intensity increments, which are problematic when testing individuals with either high or low CF levels. Individuals with low CF levels, and in particular, certain clinical populations, might not be able to adjust quickly to large and sudden increments in exercise intensity. This might cause early local muscle fatigue and a premature test termination. Individuals with high CF levels benefit from the use of ramp tests because they allow better discrimination of those parameters, namely ventilatory threshold and $\dot{V}O_2$max, that are essential for prescribing an effective exercise program. Readers are directed to the reviews of Myers and Bellin (26) and Keir et al. (14) for further details regarding ramp protocols.

Although it may be appealing due to its simplicity, using a standardized GXT protocol to test the CF of different individuals will result in GXTs with a duration that varies greatly between subjects. As a consequence, fitter individuals will have to exercise longer than those who are less fit. Being able to choose a GXT protocol of an appropriate duration is of paramount importance for exercise professionals. Indeed, although the appropriate duration of a GXT that best allows the attainment of $\dot{V}O_2$max is open to debate (20), several international associations (5,6,12) recommend that the overall test duration should be between 8 and 12 minutes. This can be achieved by tailoring the intensity increments of the GXT to the individual's estimated CF level (9,10). However, finding such a method in the literature and then implementing it in practical terms may be difficult and time-consuming, and thus may constitute a barrier for many exercise professionals.

PURPOSE

This article aims to provide simple and ready-to-use Microsoft Office Excel spreadsheets that allow exercise professionals, researchers, practitioners, and clinicians to create individualized GXTs. The spreadsheets provided in this article can be a powerful tool for many exercise professionals, especially those who can use metabolic carts to perform indirect calorimetry tests. The spreadsheets can automatically create tailored GXT protocols without the need for exercise professionals to perform any calculations. The procedures used to estimate the appropriate GXT protocols are based on the latest validated studies and are all performed automatically by the macros included within the spreadsheets. This automated procedure makes it possible to create walking, running, and cycling GXT protocols tailored to the single subject with only a few clicks of a mouse. The procedures are described in detail herein, and the Microsoft Office Excel files and scripts needed to create the GXT protocols are available as Supplemental Digital Content (SDC).

PROCEDURES

Using Excel (Microsoft Office Excel, v.2018), we created simple scripts to automate the overall procedure for estimating $\dot{V}O_2$max and for creating a personalized GXT protocol in a ready-to-use form. The Excel spreadsheets (Walking GXT [kmph], Supplemental Digital Content 1, http://links.lww.com/SCJ/A289; Walking GXT [mph], Supplemental Digital Content 2, http://links.lww.com/SCJ/A290; Running GXT [kmph], Supplemental Digital Content 3, http://links.lww.com/SCJ/A291; Running GXT [mph], Supplemental Digital Content 4, http://links.lww.com/SCJ/A292; Cycling GXT [W], Supplemental Digital Content 5, http://links.lww.com/SCJ/A293; Cycling GXT [kgmpmin], Supplemental Digital Content 6, http://links.lww.com/SCJ/A294) provided in this article allow exercise professionals to create individualized GXT protocols without having to make any calculations (for each exercise mode, we also created the following brief video tutorials: Walking GXT video tutorial, Supplemental Digital Content 7, http://links.lww.com/SCJ/A286; Running GXT video tutorial, Supplemental Digital Content 8, http://links.lww.com/SCJ/A287; Cycling GXT video tutorial, Supplemental Digital Content 9, http://links.lww.com/SCJ/A288). The procedures and formulas performed by the spreadsheets are shown in the Figure and explained in detail in the section "The development of GXT protocols."

The selected protocols are designed to (a) estimate $\dot{V}O_2$max (using a nonexercise estimation model), (b) allow users to make appropriate and individualized work rate increments during the GXT by selecting the appropriate initial and final exercise intensities (using metabolic equations from the American College of Sports Medicine [ACSM] (3) to convert $\dot{V}O_2$ into work rates such as treadmill speed and grade or bike wattage), and (c) measure the actual $\dot{V}O_2$max.

The Excel spreadsheets, provided as SDCs, can create 3 GXT protocols according to the latest literature on walking (9), running (10), and cycling (9) GXTs.

Before using the Excel spreadsheets to create the GXT protocols, the exercise professionals are directed to the sections "When can we use the GXT?" and "Exercise protocol selection" to ensure that the GXTs proposed in this article are appropriate for their clients and to choose the most suitable exercise protocol for each individual.

THE DEVELOPMENT OF GRADED EXERCISE TEST PROTOCOLS

The procedures explained below, and schematically shown in the Figure, have been implemented in the Excel spreadsheets to create individualized GXT walking, running, and cycling protocols that can be tailored to the subject being

PRELIMINARY PHASE

- Exercise protocol selection
  - Walking; Running; Cycling
- Information collection
  - Age; Gender; Height; Body mass; Physical activity level
- Computing the estimated maximal oxygen uptake ($e\dot{V}O_{2max}$)
  - $e\dot{V}O_{2max}$ computed using the non-exercise model

GXT PROTOCOL CREATION

Intensity	Walking GXT	Running GXT	Cycling GXT
Warm-up ($_{WU}$)	S_{WU} = 5.0 km/h G_{WU} = 0	$S_{WU} = S_F \times 0.4$ G_{WU} = 0	PO_{WU} = 0 W
Initial ($_{I}$)	S_I = 4.0 km/h $G_I = ((e\dot{V}O_{2max} \times 0.6) - 3.5 - (0.1 \times S_I)) / (1.8 \times S_I)$	$S_I = S_F \times 0.5$ G_I = 0	PO_I = 30 W
Stage ($_{ST}$)	$S_{ST} = (S_F - S_I) \times T + S_I$ $G_{ST} = (G_F - G_I) \times T + G_I$	$S_{ST} = (S_F - S_I) \times T + S_I$ G_{ST} = 0	$PO_{ST} = (PO_F - PO_I) \times T + PO_I$
Final ($_{F}$)	S_F = 6.0 km/h $G_F = (e\dot{V}O_{2max} - 3.5 - (0.1 \times S_F)) / (1.8 \times S_F)$	$S_F = (e\dot{V}O_{2max} - 3.5) / 0.2$ G_F = 0	$PO_F = (e\dot{V}O_{2max} - 7) / 1.8 \times BM / 6.12$

Figure. Procedures and formulas performed by the Excel spreadsheets for determining the work rates of the walking, running, and cycling GXT protocols using a nonexercise model (PRELIMINARY PHASE) and the ACSM's walking, running, and cycling metabolic equations (GXT PROTOCOL CREATION). GXT = graded exercise test; S = speed (in m $\times$ min^{-1}), unless specified; G = grade (expressed in decimal form); PO = power output (in Watt); BM = body mass (in kg); T = time elapsed from the beginning of the test (warm-up excluded) divided by 10 minutes.

tested. Using the spreadsheets, exercise professionals can easily perform all the following steps, without having to perform any calculations, to create a personalized protocol that can be used to perform the GXT. The spreadsheets and the video tutorials explaining their use in detail are provided as SDCs (see exercise-specific procedures below).

First, $\dot{V}O_2$max is estimated using the nonexercise model proposed by Matthews, Heil, Freedson, and Pastides (19), which has been cross-validated (17,18) and shown to be accurate in estimating $\dot{V}O_2$max (9,10). The nonexercise model (19) estimates the $\dot{V}O_2$max based upon several individual characteristics (i.e., age, sex, height, and body mass) and the subject's physical activity level in the past 30 days, measured on a progressive scale from 0 to 7. The following specific procedures are then applied for the design of Walking, Running, and Cycling GXT protocols.

Walking graded exercise test. The Walking GXT protocol is characterized by changes in treadmill speed and grade. The test starts with a 3-minute warm-up at 5.0 km/h and 0% grade. Then, a personalized GXT protocol starts according to the indications proposed by Cunha, Midgley, Montenegro, Vasconcellos, and Farinatti (9). Briefly, the treadmill speeds are set at 4.0 km/h in the first stage (initial speed) and at 6.0 km/h in the estimated final stage (final speed). Then, the grade yielding the estimated $\dot{V}O_2$max (final grade) is calculated for a walking exercise at 6.0 km/h (final speed) according to the ACSM's walking metabolic equation (3). The initial grade of the protocol is computed as the grade yielding 60% of the estimated $\dot{V}O_2$max when walking at 4.0 km/h (initial speed) according to the ACSM's walking metabolic equation (3). Finally, the grade and speed increments of each 1-minute stage are calculated as the difference between the final and initial values of grade and speed divided by 10 minutes and multiplied by the number of minutes elapsed from the beginning of the test (warm-up excluded) to the beginning of that given stage.

The Walking GXT protocol can be created with both km/h and mph measurement units using the SDC 1 (http://links.lww.com/SCJ/A289)–Walking GXT (kmph) and SDC 2 (http://links.lww.com/SCJ/A290)–Walking GXT (mph), respectively (see SDC 7, http://links.lww.com/SCJ/A286–Walking GXT video tutorial).

Running graded exercise test. The Running GXT protocol is characterized by changes in speed, whereas the grade of the treadmill is kept constant at 0% throughout the test. This personalized protocol is designed according to the indications proposed by da Silva et al. (10). The original protocol did not include any warm-up; however, in the protocol proposed in this article, we decided to include a 3-minute warm-up at 40% of the estimated maximal treadmill speed because it is common practice to warm-up before a maximal GXT (see below for details).

According to da Silva et al. (10), the speed yielding the estimated $\dot{V}O_2$max (i.e., the final speed) is calculated from the estimated $\dot{V}O_2$max according to the ACSM's running metabolic equation (3), and the initial speed of the protocol is set at 50% of the final speed. The speed increment of each 1-minute stage is calculated as the difference between the final and initial speed divided by 10 minutes, multiplied by the number of minutes elapsed from the beginning of the test (warm-up excluded) to the beginning of that given stage.

The Running GXT protocol can be created with both km/h and mph measurement units using the SDC 3 (http://links.lww.com/SCJ/A291)–Running GXT (kmph) and SDC 4 (http://links.lww.com/SCJ/A292)–Running GXT (mph), respectively (see SDC 8, http://links.lww.com/SCJ/A287–Running GXT video tutorial).

Cycling graded exercise test. The Cycling GXT protocol starts with a 3-minute warm-up at 0 W, followed by a personalized protocol designed according to the indications proposed by Cunha et al. (9).

The work rate yielding the estimated $\dot{V}O_2$max (i.e., the final W) is calculated from the estimated $\dot{V}O_2$max according to the ACSM's cycling metabolic equation (3), and the initial work rate of the protocol is set at 30 W. The W increment of each 1-minute stage is calculated as the difference between the final and initial work rate divided by 10 minutes and then multiplied by the number of minutes elapsed from the beginning of the test (warm-up excluded) to the beginning of that given stage. The cycling cadence should be maintained between 55 and 65 rpm. When creating a cycling GXT, exercise professionals must consider the ergometer being used for the test. Indeed, electronically braked ergometers can allow you to keep the power output (PO) relatively close to the target PO that has been set, even if small variations in the cycling cadence occur. However, if mechanically braked ergometers are used, variations in the cycling cadence during the test will be reflected directly in the PO, which will diverge from the target PO. Therefore, exercise professionals should set the cycling cadence for each subject (we recommend about 60 rpm), record it, and keep it as constant as possible throughout the test.

The Cycling GXT protocol can be created with both Watt and kilogram meters per minute measurement units using the SDC 5 (http://links.lww.com/SCJ/A293)–Cycling GXT (W) and SDC 6 (http://links.lww.com/SCJ/A294)–Cycling GXT (kgmpmin), respectively (see SDC 9, http://links.lww.com/SCJ/A288–Cycling GXT video tutorial).

Using the above-mentioned approaches to create Walking, Running, and Cycling GXTs should allow attainment of the final exercise intensities, hence the estimated $\dot{V}O_2$max, at approximately the 10th minute of the tests (9,10).

To confirm the achievement of true $\dot{V}O_2$max, several authors (21–24,28) recommend performing the so-called verification stage (VS). Briefly, a VS is a maximal exercise test performed at a constant maximal intensity. VSs are usually performed after a resting period (e.g., 20 minutes) from the end of the GXT, and they are composed of a warm-up and maximal exercise phase. The maximal exercise phase is performed at a constant intensity for as long as possible to exhaustion; the exercise intensity is computed as a percentage (e.g., 105%) of the maximal exercise intensity achieved during the GXT. Due to the simplicity of the procedures, in the present article, we did not provide automated protocols for creating VSs.

WHEN CAN WE USE THE GRADED EXERCISE TESTS?

As mentioned above, the first step in the design of each GXT protocol (9,10) is estimating $\dot{V}O_2$max using a nonexercise model (19), which has been validated in a large sample of men and women of a broad age range (19–79 years) and shown to be accurate and reliable in estimating $\dot{V}O_2$max and GXT duration (9,10). However, the nonexercise estimation model has shown a tendency to underestimate CF in individuals with high CF levels and to overestimate CF in individuals with low CF levels (9,10,19). Such errors, although rare in healthy individuals, could be an issue when GXTs are designed for athletes or unfit and clinical populations. Moreover, it is noteworthy that the Walking and Cycling GXTs have been validated solely on a sample composed of healthy young adult males (9); therefore, their validity for other populations is yet to be confirmed.

ACSM's metabolic equations are commonly used by exercise practitioners to convert work rates, such as walking and running speed and grade and cycling PO, into $\dot{V}O_2$. However, although the ACSM's metabolic equations have been proven to accurately estimate the final exercise intensity of the GXT protocols from the estimated $\dot{V}O_2$max (9,10), converting work rates into $\dot{V}O_2$ using the ACSM's metabolic equations has some limitations. Indeed, the equations allow a proper estimation of $\dot{V}O_2$ from work rates only during steady exercise (i.e., when the exercise intensity is kept constant for a prolonged period) and within certain work rate ranges (3). Exercise professionals who do not have access to a metabolic cart can still use the SDCs to estimate $\dot{V}O_2$max using the nonexercise model and can thus create a GXT protocol. However, they should not convert the maximal exercise intensity attained during the individualized GXT into $\dot{V}O_2$ using the ACSM's metabolic equations because it will yield estimation errors.

The spreadsheets allow the automatic creation of incremental exercise protocols divided into 1-minute stages. However, if necessary, any ramp protocol can be easily designed by dividing the difference between the final and initial intensities (obtained from the spreadsheets) by the desired test length (e.g., 10 minutes), and multiplying that figure by the desired length of each stage (e.g., 10 seconds). Creating incremental exercises with short stages can be done easily when the ergometer and metabolic cart are interfaced with each other. In such a setup, the metabolic cart software will usually allow the creation of ramp protocols by entering some essential information such as initial speed and final speed, and desired test and stage length. Exercise professionals, using the spreadsheets, can easily personalize the desired ramp protocols by entering the required information in the software.

The SDCs can also be modified, to a certain extent, to adapt the GXT protocols proposed in this article to the specific needs of the exercise professional. For more information about this possibility, please contact the corresponding author.

EXERCISE PROTOCOL SELECTION

Choosing the exercise protocol can be challenging and starts with the selection of the exercise testing mode.

Treadmill walking or running and stationary cycling testing modes have advantages and disadvantages. The motor-driven treadmill exercise test usually elicits higher physiological responses (e.g., $\dot{V}O_2max$) than the cycle ergometry (4). Moreover, cycle ergometry exercise testing may be a less familiar mode of exercise for some individuals, and it could yield a lower $\dot{V}O_2peak$ due to localized muscle fatigue of the quadriceps muscle group. Indeed, Myers et al. (27) reported that among patients limited by angina on the treadmill test, 26% were limited by leg fatigue during cycle ergometer testing, making the latter test less sensitive for the detection of angina.

Motor-driven treadmills provide a familiar exercise modality for many subjects. However, treadmill tests have higher equipment costs than cycle ergometer tests and can make some measurements (e.g., blood pressure and electrocardiogram) more difficult, particularly when an individual is running. Moreover, the ability to use the treadmill safely could be a limitation for certain subjects with orthopedic, peripheral vascular, or neurological limitations that restrict weight-bearing activities; in such cases, cycle ergometers provide a non–weight-bearing test modality that better suits the needs of those subjects (25).

When choosing between treadmill walking or running tests, the primary criterion is the subject's estimated fitness level, combined with the exercise intensity ranges in which the subject prefers walking or running, which can vary greatly among subjects based upon several individual characteristics (e.g., height, biomechanical characteristics, etc.). Indeed, a taller individual may walk comfortably at a typical running speed, whereas a shorter individual may prefer running at a typical walking speed. When undecided between walking or running GXT, exercise professionals can use the SDCs to create both walking and running GXT protocols. They can then evaluate which test is the most appropriate for each subject by assessing whether it is reasonable to expect that individual to exercise at the intensities created for the walking and running GXT protocols. For example, in subjects with low estimated fitness levels, the running test protocols might not be feasible due to the low maximal speed achievable by such subjects, which would force the subjects to walk during most of the test. On the contrary, in subjects with high estimated fitness levels, the walking test protocols might require steep grades (the use of which is commonly associated with exercise-limiting symptoms such as muscle strain or discomfort (7) and may be steeper than the maximal grade allowed by the treadmill) and high speeds (which can make walking uncomfortable or impossible and force the subject to begin running).

HOW TO USE THE SPREADSHEETS

The following steps should be followed to create a GXT protocol (for more detailed explanations, please watch the tutorials: SDC 7 (http://links.lww.com/SCJ/A286)–Walking GXT video tutorial; SDC 8 (http://links.lww.com/SCJ/A287)–Running GXT video tutorial; SDC 9 (http://links.lww.com/SCJ/A288)–Cycling GXT video tutorial):

- Select the desired exercise modality (i.e., Walking, Running, or Cycling GXT) and measurement units, then open the corresponding spreadsheet;
- Accurately fill in all the yellow cells on "Sheet1";
- Click on the "Create GXT" button.

The sheet of the individualized GXT protocol will then appear (this sheet can be saved and printed).

SUMMARY

The spreadsheets provided in this article allow practitioners, researchers, and clinicians to quickly create up-to-date validated GXT protocols for different exercise modalities without having to perform any calculations. Moreover, the spreadsheets not only make it possible to create reproducible and validated GXT protocols, but also constitute a cost-free procedure that could be implemented easily in any facility where GXT protocols are performed.

We believe that the automated procedures available as SDCs will be a time-saving, powerful, practical, immediate, and useful tool for exercise professionals when they need to adopt a nonstandardized GXT protocol to their clients.

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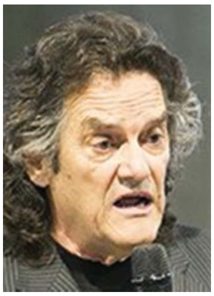
Carlo Ferri Marini *is a postdoctoral researcher in the Department of Biomolecular Sciences–Division of Exercise and Health Sciences, at the University of Urbino Carlo Bo.*

Luca Correale *is a postdoctoral researcher in the LAMA (Laboratory of Adapted Motor Activity), Department of Public Health, Experimental Medicine & Forensic Science, at the University of Pavia.*

Vittoria Carnevale Pellino *is a PhD student in the LAMA (Laboratory of Adapted Motor Activity), Department of Public Health, Experimental Medicine & Forensic Science, at the University of Pavia.*



Ario Federici *is a full professor in the Department of Biomolecular Sciences–Division of Exercise and Health Sciences, at the University of Urbino Carlo Bo.*

Matteo Vandoni *is a research fellow in the LAMA (Laboratory of Adapted Motor Activity), Department of Public Health, Experimental Medicine & Forensic Science, at the University of Pavia.*

Francesco Lucertini *is a research fellow in the Department of Biomolecular Sciences–Division of Exercise and Health Sciences, at the University of Urbino Carlo Bo.*

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