Original Article

Cardiometabolic and perceptual responses to maximal exercise: Comparing graded walking to running

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ABSTRACT

Graded exercise testing on a treadmill can be accomplished by increasing speed and/or grade. The purpose of this study was to compare cardiometabolic responses during graded walking and ungraded running. Thirty healthy, active adults (21 females, 9 males; VO_{2peak} = 39.9 ± 5.4 ml/kg/min) completed two counterbalanced maximal exercise tests (Walk Max & Run Max). Walk tests started at a self-selected brisk speed, increased grade by 2% each minute. Run tests started at 3.5 mph and increased speed by 0.5 mph each minute. Expired gases, HR, overall RPE (RPE-O), legs only RPE (RPE-L), and RER were assessed. Data were analysed using dependent t-tests. Walk Max and Run Max protocols yielded results indicating maximal effort. VO_2 was higher for the Run Max protocol ($p < .05$; ES = 0.4). RPE-L was higher for the Walk Max protocol ($p < .05$; ES = 0.4). RPE-O was not different between protocols ($p > .05$). RER was also higher for the Walk Max protocol ($p < .05$; ES = 0.7). Total exercise time for both protocols was similar ($p > .05$). Max protocols delivering work by walking and running are both viable and provide options to suit the circumstances and/or preferences of the patient/client. Walk and run protocols can be appropriate for young, healthy, and active individuals. Walk protocols may limit participant anxiety related to falls and thus has the potential to increase exercise self-efficacy. Walk protocols are also an excellent choice when the participant cannot or should not perform a run-based protocol.

Keywords: Exercise; Fitness; Assessment; Testing; Physiology.

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INTRODUCTION

Graded exercise testing for the determination of maximal aerobic capacity has been in use for decades and remains a primary tool in research, clinical practice, and sport performance. A traditional exercise test utilizing predetermined workloads for specific time periods remained largely unchallenged but criticism has arisen in recent years. The primary concern is that the graded and maximal nature of conventional testing is both unnatural and does not allow for the person being tested to participate in setting the pace during the protocol (Noakes, 2008). These types of criticisms have given rise to self-paced, perceptually-regulated exercise testing that is able to achieve equal or greater maximal workloads and metabolic rate (Mauger & Sculthorpe, 2012; Hanson et al., 2016). However, traditional graded exercise tests with defined workload changes remain a staple of exercise testing and are especially useful in contexts such as integrative biology, epidemiology, and clinical medicine (Shephard, 2009). Within traditional testing approaches, ramp protocols appear to offer an approach to treadmill testing that is less intimidating, avoiding the sudden and rapid work rate changes associated with commonly used step protocols (Myers et al., 1991; Wolthuis et al., 1977). Recognizing the individual benefits of self-selection and ramp-style protocols, combining these approaches may be especially valuable in increasing self-efficacy for exercise testing in general and clinical populations with less exercise and treadmill experience.

The long history of maximal exercise testing has allowed for the development of numerous protocols for general and specific applications, with treadmills and cycle ergometers representing the most common modalities (Banerjee et al., 2012; Beltz et al., 2016). Research comparing cycle and treadmill modalities indicates that treadmill testing produces peak oxygen consumption (VO_2) values that exceed cycle ergometry testing by 10-20% in most populations (Muscat et al., 2015). This discrepancy can be partially explained by local fatigue experienced within the leg musculature resulting in test termination before one reaches maximal cardiovascular limits (Keeney et al., 2015). While cycle ergometry testing is limited primarily by ergometer resistance measured in watts, treadmill testing has two important variables that make up workload during testing, namely treadmill speed and grade. Among the first graded maximal exercise protocols developed for exercise testing was the Bruce protocol, which starts with a slow speed and significant grade and increases both speed and grade every three minutes until exhaustion (Bruce et al., 1963). This test was developed specifically for clinical exercise testing in cardiac populations with low cardiovascular capacity but remains a common treadmill protocol both inside and outside of clinical domains but is far from ideal in terms of protocol configuration. Another prominent early test was the Balke protocol, which initiates at a fixed walking speed with no grade and increases grade each minute until exhaustion (Balke & Ware, 1959). This protocol is markedly different from the Bruce protocol because it does not require jogging or running and maintains a steady walking speed and also because the stages are much shorter. Other notable treadmill protocols include the Ellestad (Ellestad et al., 1969) and Naughton (1978) maximal tests, each of which utilizes a combination of speed and grade to induce exhaustion. Importantly, the Bruce, Balke, and Ellestad protocols have been shown to produce similar maximal VO_2 and heart rate responses (Pollock et al., 1976). Noteworthy is that standard protocols aiming to create maximal work primarily through grade increases are less well-established and limited to the Balke protocol, though walk-only protocols have been developed and employed in research laboratories and appear in published research. Two important considerations and potential limitations related to the Balke protocol is that the length of the test can be much longer than the recommendation of 6-12 minutes (ACSM, 2018), and having a set walking speed for everyone is not ideal given differences in leg length, walking speed preference, and fitness.

Determination of the specific protocol to be used in maximal exercise testing is highly dependent upon factors such as the health and fitness level of the exerciser, test safety, available parameters of the exercise equipment, and whether the goal is evaluation of clinical considerations or for general evaluation of fitness to inform exercise prescription, among others (ACSM, 2018). With respect to treadmill testing and the decision on whether to utilize a protocol that delivers work primarily by grade or speed, or some combination of both, the preferences and needs of the individual exerciser are highly relevant. Testing situations that are primarily clinical in nature are more likely to utilize a protocol that does not require running because walking enhances the quality of cardiovascular monitoring, specifically blood pressure and electrocardiography. Likewise, some test participants may be uncomfortable with any protocol that requires running, perhaps most notably for individuals who lack familiarity with running in general and/or running on a treadmill in particular. These considerations combined with lower peak metabolic rates on cycle ergometers demonstrate the potential value of walk-based protocols. In contrast, run-based protocols, and especially those with limited grade, may be more desirable for individuals unaccustomed to exercising against a severe grade or when the nature of the exercise test is to identify overground speeds associated with exercise prescriptions tailored to individual fitness. These distinctions are important because research demonstrates that ungraded running and graded walking produce different cardiovascular and metabolic responses when conducted at the same rating of perceived exertion (Kilpatrick, et al., 2009). Importantly, relatively little is known about how treadmill protocols utilizing speed to induce maximal work differ from protocols utilizing grade to induce maximal work, especially in regard to perceptual responses. Therefore, the purpose of the present study was to investigate the cardiometabolic and perceptual responses systematically with the goal of better understanding potential differences associated with maximal exercise.

METHODS AND MEASURES

Participants and Research design

Thirty participants (21 females, 9 males) at a large university in the United States completed this project. All participants were currently engaged in aerobic and/or resistance training programs at least three days per week, had a body mass index (BMI) that was less than 35, and were non-smokers. Participants completed three laboratory visits, each separated by at least 24 hours and visits were completed within 2 weeks. The first visit included medical screening and informed consent. The second and third visits included the determination of peak oxygen consumption (peak VO_2) and represent the experimental trials. One experimental trial was a maximal test achieved by way of graded walking (Walk Max) and the other experimental trial was a maximal test achieved by way of ungraded running (Run Max). The two experimental trials were completed in a counterbalanced manner. All procedures were approved by the university institutional review board.

Screening

The first visit to the laboratory included the completion of informed consent, health history questionnaire, and measurement of height, body weight, heart rate (HR), and blood pressure (BP). Participants in this study were instructed to avoid alcohol, caffeine, and all tobacco products for three hours prior to testing (ACSM, 2018). Body composition was also assessed by way of bioelectrical impedance (InBody, Cerritos, CA). Participants were medically screened by a licensed physician assistant to determine the presence of contraindications to exercise, with a specific focus on orthopaedic, cardiovascular and pulmonary conditions that would preclude participation in the research study.

Metabolic testing overview

The experimental trials were conducted utilizing progressive, multistage protocols on a motorized treadmill (Full Vision, Newton, KS) in random order on separate days. Measurements of HR, BP, ratings of perceived exertion (RPE), and respiratory gases were monitored in accordance with standard exercise testing guidelines (ACSM, 2018). Expired gases were collected using a neoprene mask and analysed continuously using a calibrated metabolic measurement cart (Medical Graphics, St. Paul, MN). Peak VO_2 was identified as the largest volume of O_2 consumed per minute during the test. The primary criterion for maximal effort was a plateau in VO_2, defined as a workload increase without a significant increase in oxygen consumption (defined as < 150 ml/min). Secondary criteria for maximal effort were achievement of at least two or more of the following: a peak HR of at least 90% of age-predicted maximal HR (APHRmax), a peak RPE of at least 18 (on a 6-20 scale), and a peak respiratory exchange ratio (RER) of at least 1.10.

Walk-Based maximal testing

The graded walking exercise test initiated at 0% grade and a self-selected walking speed (mean of 3.2 ± 0.4 mph, range = 2.0 – 3.8 mph) and grade increased by 2% each minute. Speed remained constant until grade reached 24%, at which time the grade became fixed and speed increased by 0.5 mph each minute thereafter. The speed increase was required for three participants and ranged from an increase of 0.5-1.0 mph, with walking speed remaining below 4.0 mph for all participants. The speed increase component of the design was utilized because the treadmill could not achieve grades higher than 25%, which is common for most commercial and research devices. The test continued until volitional exhaustion and included verbal encouragement.

Run-Based maximal testing

The ungraded running exercise test initiated at 3.5 mph for all participants and increased by 0.5 miles/hour (0.8 kilometres/hour) each minute. Grade remained constant until speed reached 8.5 mph, at which time the speed became fixed and grade increased by 2% each minute thereafter. The speed increase was required for 11 participants and ranged from 2-4%. The grade increase component of the design was utilized as a safety precaution so as to not require these participants, most of whom were not experienced in running on a treadmill, to run at speeds that might produce a relatively high fall risk. The test continued until volitional exhaustion and included verbal encouragement.

Data collection

Primary variables of interest for this study included: VO_2, HR, and RPE. HR was measured using a chest monitor (Polar, Lake Success, NY). RPE was measured using the 15point Borg 6-20 scale (Borg, 1998), which ranges from 6 (no exertion at all) to 20 (maximal exertion). RPE assessment included measurement of overall exertion (RPE-O) and leg-specific exertion (RPE-L). The perceived exertion scale was explained to the participants in advance of exercise testing, with special emphasis on the difference between overall and leg-specific exertion. Both HR and RPE were assessed and recorded each minute during exercise and at peak work. VO_2 was recorded each minute and at peak work using a multiple breath averaging procedure.

Statistical analysis

Data were analysed using SPSS 26 and proceeded in three phases. The first phase included a descriptive analysis of the sample. The second phase included a descriptive evaluation of criteria for maximal effort. The third phase included a series of dependent t-tests comparing the Walk and Run protocols. Criterion for significance was set at $p < .05$. Significant differences are reported to the lowest appropriate criterion level. Mean differences were utilized to determine effect size (ES) differences, where values of 0.2, 0.5, and 0.8 represent small, medium, and large effects, respectively (Cohen, 1992).

RESULTS

Sample characteristics

Descriptive analysis of study participants suggests the sample was young (mean age ± SD = 23.2 ± 4.9 years), active (2.6 ± 1.5 days per week of moderate-to-vigorous aerobic exercise and 3.2 ± 1.7 days per week of muscle-strengthening exercise), normal-to-overweight (BMI = 25.4 ± 3.5), normal-to-overfat (27.2 ± 8.5% fat). HR and blood pressure (BP) values at rest were normal (HR = 69.3 ± 12.4 beats per minute; systolic BP = 116.8 ± 7.6 mmHg; diastolic BP = 73.2 ± 4.9 mmHg).

Criteria for maximal effort

Descriptive analysis of peak intensity exercise data provides information related to whether or not maximal effort was put forth during testing. A review of VO_2 data at the conclusion of the exercise test noted that a plateau was not routinely observed but was more common in the Run Max protocol. In contrast, a review of prominent secondary criteria such as HR, RER, and RPE data measured during both Walk Max and Run Max protocols provide confirmation that a maximal effort was routinely provided by participants. Specifically, evaluation of physiological and psychophysiological testing data indicates that maximal effort was achieved by the vast majority of all participants for both Walk Max and Run Max protocols. These data are summarized in Table 1.

Table 1. Criteria for maximal effort.

	Walk Max	**Run Max**
VO_2 (< 150 ml/min)	27% (n = 8)	50% (n = 15)
HR (90+% APHRmax)	87% (n = 26)	80% (n = 24)
RER (1.10+)	87% (n = 26)	77% (n = 23)
RPE (18+)	77% (n = 23)	73% (n = 22)

Walk and run protocol comparison

The primary analytic consideration was the comparison of cardiometabolic and perceptual data at maximal effort for the two maximal protocols. VO_2 was higher for the Run Max protocol than the Walk Max protocol ($p < .01$; ES = 0.4). Total exercise time was similar for the two protocols ($p > .05$). Likewise, HR was similar for the two protocols ($p > 0.05$).

Evaluation of exertion indicated that RPE-O was similar for the protocols ($p < .05$) but RPE-L was higher for the Walk Max protocol ($p < .05$; ES = 0.4). Evaluation of RER indicates that the Walk Max protocol produced higher values than the Run protocol ($p < .01$; ES = 0.7). These data are summarized in Table 2.

Table 2. Cardiometabolic and perceptual responses.

	Walk Max	**Run Max**	**Significance**	**ES**
VO_2 (ml/kg/min)	37.6 ± 5.1	39.9 ± 5.4	p < .01	0.4
Total Time (mins)	10.9 ± 1.9	10.1 ± 2.2	p = .09	0.4
Ve (L/min)	86 ± 21	81 ± 24	p = .01	0.2
HR (beats/min)	189 ± 12	191 ± 13	p = .45	0.2
RPE-O (Borg 6-20)	18.6 ± 1.6	18.8 ± 1.2	p = .32	0.1
RPE-L (Borg 6-20)	19.1 ± 1.4	18.4 ± 1.7	p = .04	0.4
RER	1.22 ± 0.08	1.17 ± 0.05	p < .01	0.7

DISCUSSION

The present experiment was designed to investigate the cardiometabolic and exertional responses to maximal exercise testing at peak work. Recognizing that research has indicated novel testing protocols can produce equivalent or greater physiological responses than more traditional protocols (Mauger & Sculthorpe, 2012; Hanson et al., 2016), the timing is right to further explore the utilization of new and different protocols that can be tailored to the unique needs of particular populations. The current study design produced two unique testing protocols to assess how a run-based maximal protocol compares to a walk-based maximal protocol conducted at a self-selected walking speed. Findings related to maximal criteria indicate that maximal effort was provided by the vast majority of research participants. Most importantly, the exercise tests produced assessments that were similar in terms of total exercise time and heart rate (HR) responses, but somewhat different metabolic and perceptual responses.

Maximal exercise test design included grade and speed increases each minute that were expected to be roughly equivalent based on standard metabolic equations (ACSM, 2018) and ultimately yielded exercise tests that were of very similar duration. More specifically, the 2% increase and 0.5 mile/hour increases each minute yielded exercise tests durations that were on average 10-11 minutes. Evaluation of HR data suggest the cardiovascular response at maximal intensity were similar at about 190 beats/min. These findings make clear that protocols delivering work via grade or speed can provide equivalent cardiovascular stress, which has important implications for a wide variety of clinical and nonclinical populations.

Consideration of metabolic data provides a varied view of how maximal walk and run tests compare. At peak exercise the run test produced VO_2 levels that were significantly higher than the walk test by approximately 5% (~0.6 MET; ~ 0.4 ES). This data suggests that slightly higher peak metabolic work rates are achievable in low-to-moderately fit adults by way of run based maximal testing than walk-based maximal testing. In contrast, evaluation of RER provides a different view, with walk-based maximal exercise tests producing higher values than run-based maximal exercise tests at peak exercise. The observed difference at peak exercise is approximately 4% (1.22 vs. 1.17; ~0.7 ES). Existing evidence that inclined exercise produces greater recruitment of the gastrocnemius muscle (Silder et al., 2012) points to the possibility that the increased RER observed during graded walking may indicate that maximal graded walking produces greater acidosis than ungraded maximal running. One other finding of interest is observed for RPE responses. At peak exercise the two tests produced similar overall RPE responses, but the walk test produced higher responses for leg-specific RPE (19 vs. 18; ~0.5 ES). These findings suggest that exertion during walk-based maximal testing increases to a greater extent than run-based testing for leg-specific RPE.

An important take away from this study is that walk-based maximal testing could be more viable in general population settings. Individuals who cannot or should not run due to an injury, personal preference, or medical diagnosis may benefit from a walking max test. More specifically, this type of testing may be a good option for individuals who need to reduce joint loading relative to running (Hialt et al., 1994; Swain et al., 2016). Likewise, graded walking when compared to running facilitates more desirable joint mechanics that may be more physically comfortable for joints that often experience pain or suffer from cartilage degeneration and specific types of osteoarthritis (Haggerty et al., 2014). Also important is that results from this study make clear that an incline walking-based test can produce VO_{2max} values that are closer to run-based VO_{2max} values than that which is observed with cycle ergometer testing. The markedly lower metabolic response on a cycle ergometer may be due to the specific nature of cycling, which is likely to produce optimal metabolic responses only in individuals who are highly experienced using bicycles (Moreira-da-Costa et al., 1989). Though using cycle ergometers for aerobic testing is common in many testing facilities, this approach is likely only best for individuals who are well-practiced on bike modalities, and likely less desirable for the many individuals who are naïve to cycle-based exercise. As such, inclined walking protocols can be used in place of a cycle ergometer and are likely to produce maximal effort and capacity for a wide range of clients and patients. Noteworthy is that inclined walking is a more natural form of movement for participants and patients over biking, which may further explain the potential benefits of walk-based ergometry testing. The use of incline-based protocols is perhaps especially appropriate for low-to-moderately fit individuals who are unlikely to achieve maximal grades and/or require additional speed to induce maximal exercise. Finally, inclined walk protocols are likely useful for individuals with orthopaedic or other mobility concerns, making it potentially a very functional testing option. Broadening exercise testing to include more walk based protocols allows for more options that increases the opportunity to properly establish health and fitness. One particularly useful aspect of the protocol employed in the present study is the provision of choice for a preferred and personalized walking speed, which may lead to a more comfortable and self-controlled exercise testing experience.

Strengths of this study include internal validity and the novelty of the research question. The author team is unaware of published research that has directly compared two maximal treadmill protocols that utilize entirely different approaches for achieving maximal work, one via incline and the other via speed. The findings provide the first test of this type of research question and also provides a framework from which to develop other designs interested in exploring the similarities and differences amongst the varied treadmill tests in use in clinical, athletic, and research contexts. The inclusion of the comparison of overall RPE against leg specific RPE in particular represents an interesting advance in how maximal protocols might be considered. By the implementation of using both RPE scales it allowed for a better understanding of the participants overall RPE and leg-specific RPE. Using both RPE scales allowed further clarification on using the incline and the overall effect of how grade of a treadmill impacts RPE.

Limitations focus primarily on the sample, which is relatively small and mostly female. Similarly, the sample was not very aerobically fit, which is an important consideration because more fit individuals would be more likely to require additional grade near the conclusion of the run test and additional speed at the end of the walk test. It seems that a pure or near-pure walk test for aerobic fitness would be more appropriate for low-to-moderately fit individuals than more fit population segments that would require large speed increases given that most commercial grade treadmills max out at 25% grade. However, the walk-based protocol utilized in the present study would likely be very reasonable for the vast majority of the general population. Likewise, insertion of grade near the end of the run protocol after the treadmill reached relatively high speeds produces a similar problem, which can be mitigated by allowing participants to run at faster speeds before increasing treadmill grade. It should also be mentioned that the study sample resided in an area that is relatively flat, with only modest hills. These local conditions suggest that it is at least possible that the findings might have been somewhat different if the sample was more accustomed to walking in hilly terrains, potentially altering both exertion and metabolic responses.

CONCLUSION

The current study provided an evaluation of a novel research question regarding the cardiometabolic and perceptual responses to maximal treadmill exercise tests that differed on the use of grade or speed to increase work. The design and associated findings create an opening for additional exploration and consideration of how different approaches to treadmill testing are designed, implemented, and tolerated with different populations and in different settings. Future research should consider a direct comparison against a cycle-based testing protocol and utilization of samples that are less aerobically fit and/or include individuals with orthopaedic or other factors that might limit exercise capacity. Future research may also compare these new and inventive protocols to the already established ones. Consideration of how athletes, patients, and the general population perceive and feel about maximal exercise testing can allow for the development of protocols that fit the particular needs of the population segment.

AUTHOR CONTRIBUTIONS

Marcus Kilpatrick and Abby Fleming: involved in data collection, writing, design, and statistical analysis. Balea Schumacher and Brian Waddell: data collection and writing.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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