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A VO_{2max} Protocol for Young, Apparently Healthy Adults

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ABSTRACT

International Journal of Exercise Science 16(4): 1257-1268, 2023. The Bruce and Astrand treadmill protocols are commonly utilized when assessing maximal oxygen consumption (VO_{2max}). However, the steep grade implemented in the protocols often leads to localized muscular fatigue, potentially causing participants prematurely to terminate the test prior to reaching their true VO_{2max}. The purpose of this study was to evaluate a Novel VO_{2max} protocol that may be better suited for young, apparently healthy populations. The Novel protocol starts at a higher speed and lower initial grade to limit lower extremity fatigue. Fifteen participants performed the Bruce, Astrand, and Novel protocols with the following maximal values recorded from each: VO_{2max}, maximal ventilation (VE_{max}), respiratory exchange ratio (RER), heart rate (HR), rating of perceived exertion (RPE) and time to exhaustion (TTE). The Novel protocol displayed substantial agreement with both criterion protocols. Mean absolute percent error (MAPE) was less than 10% indicating that the Novel protocol is a valid measurement for VO_{2max} values. Bland-Altman analysis revealed that the Novel protocol exhibited a low degree of bias, with tight limits of agreement when compared to the Bruce (bias ±95% LOA = 0.824 ± 3.163) and Astrand protocols (-0.153 ± 3.528) for VO_{2max}. A paired samples *t*-test revealed no significant differences between Novel and criterion protocols for VO_{2max}. Paired samples *t*-tests revealed that the Novel protocol had significantly lower TTE when compared to the Bruce and Astrand protocols and produced similar VO_{2max} values to that of the Bruce and Astrand. The Novel protocol may be considered a valid and time-efficient protocol.

KEY WORDS: Treadmill testing, maximal oxygen consumption, cardiorespiratory fitness, aerobic endurance

INTRODUCTION

Maximal oxygen consumption (VO_{2max}) is defined as the maximal amount of oxygen that an individual can consume and utilize within active tissues. It is generally the accepted measure of an individual's cardiorespiratory fitness and functional capacity of the heart. For these reasons,

poor cardiorespiratory fitness is indicative of physical inactivity and an increased risk of cardiovascular disease and all-cause mortality (1).

Beyond its application as a health assessment, VO_{2max} is regularly quantified in those who compete in aerobic or endurance events (1). A high VO_{2max} is the result of both central and peripheral adaptations to the respiratory, cardiovascular, and musculoskeletal systems secondary to endurance training. Whether mechanical or cellular, systematic adaptations work in tandem to improve transportation and delivery of oxygen and nutrients to the working musculature in order to use during cellular respiration. An accurate measurement of VO_{2max} allows athletes to track progress and program training by monitoring and manipulating pacing (1, 11).

In the United States, VO_{2max} is most commonly assessed on the treadmill as [1] running is a familiar form of exercise in athletic performances, and [2] the full body, weight bearing nature of upright locomotion requires high levels of muscle mass utilization (1). Numerous treadmill protocols have been developed that sufficiently challenge the oxygen transport system while minimizing localized muscular fatigue (thus interfering with volitional exhaustion). Most available protocols manipulate speed, grade, and stage duration to allow a participant to perform at their maximal aerobic capabilities. However, each treadmill protocol has limitations when applying to subgroups of populations and those with wide ranges of aerobic capabilities. These issues may introduce measurement error and a potentially flawed VO_{2max} measurement.

Of the many validated graded exercise tests available, the Bruce and Astrand are regularly used in research and applied settings. The Bruce protocol (6) modifies speed and grade every three minutes, while the Astrand protocol (4) keeps speed constant but modifies grade every two minutes. Though a widely used protocol for a variety of populations, the Bruce was originally developed to screen symptomatic patients for coronary artery disease, arrhythmias, and other cardiac complications (6, 7, 18, 22). Because the original population mostly consisted of middle-aged men with heart abnormalities (6, 22), the first two stages of the Bruce protocol are a very low speeds (walking) to minimize risk and acutely identify the presence of a cardiac complication, but with aggressive grades. The first stages (1.7 mph 10%; 2.5 mph 12%) are largely unnecessary when testing populations for functional fitness, rather than cardiovascular symptoms. The steep grade utilized in the latter stages of the Bruce protocol may induce excessive localized muscular fatigue in the lower extremities, leading to an underestimation of VO_{2max} in healthy participants (7).

The Astrand, an alternative to the Bruce, sets speed at five miles per hour (mph) for the duration of the test, which may be abnormally slow for healthy populations. Additionally, the first stage of the test is at a 0% grade, which may limit ecological validity as it does not account for wind resistance or treadmill inertia (15). Each two minute stage increases by two percent grade. Though these tests are considered valid, the identified limitations may induce measurement error and underestimation of VO_{2max} in healthy populations. A treadmill test that starts with a low grade and higher speeds may better assess a physically active cohort.

The purpose of this study was to validate a novel VO_{2max} protocol that may be better suited for healthy populations. The research team developed a Novel protocol that would present with fewer limitations, a lower chance for measurement error, and a shorter time to exhaustion. It was hypothesized that the Novel protocol would be similar to the Bruce and Astrand tests in terms of values for [1] cardiorespiratory and metabolic variables, [2] rating of perceived exertion (RPE), and [3] time to exhaustion (TTE).

METHODS

Participants

Fifteen participants between the ages of 18 to 28 years volunteered to perform three graded exercise treadmill tests. Participants were recruited from the university and surrounding community. Participants were notified of the study by word of mouth (e.g., in class announcements, emails, faculty/staff meetings). The risks and benefits of participating in the study were explained to each participant before giving consent. This study was approved by the Institutional Review Board for Human Subjects Research and was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (19).

Prior to data collection, participants completed the American College of Sports Medicine (ACSM) Exercise Pre-participation Health Screening Questionnaire (1). The questionnaire was used to ensure participants were 1) meeting the threshold for planned, structured physical activity, and 2) free of signs, symptoms, and/or known cardiovascular, metabolic, or renal disease that would prevent them from exercising to volitional exhaustion.

This study examined 15 participants during maximal exercise testing on a treadmill with mean participant characteristics shown in Table 1. The three female participants and one male participant lack body composition data.

Table 1. Individual Participant Descriptive Data.

Variable	Male (*n* = 12)	Female (*n* = 3)
Age (y)	21 ± 1.76	22.67 ± 5.03
Height (cm)	177.57 ± 5.70	172.17 ± 5.51
Weight (kg)	77.48 ± 12.03	68.2 ± 8.61
Body Mass Index (BMI)	24.5 ± 3.20	23.0 ± 1.86
Waist:Hip Ratio (WHR)	0.88 ± 0.05	0.75 ± 0.04
Body Fat (%)	13.1 ± 5.50	x

Note: Values are presented as mean ± standard deviation.

Protocol

This study employed a randomized, counterbalanced design. Participants were asked to complete three different graded exercise protocols (Bruce, Astrand, and Novel), each separated by a minimum of 48 and maximum of 96 hours. The fourth session evaluated body composition

analysis using air displacement plethysmography (BodPod, COSMED) and body circumference measurements. The duration of each lab session was approximately 20-30 minutes. The Novel protocol is described below in Table 2. Higher initial treadmill speeds were utilized to eliminate walking in the early stages of the protocol. Grade was kept low until the latter stages of the protocol to avoid excessive muscular fatigue in the lower extremities. After preliminary testing, an increase in speed by 1 mph in the first 5 stages seemed to be manageable and appropriate for participants. A sizeable increase in grade was observed following stage five to keep test duration within the recommended range of 8-12 minutes (4).

Table 2. Novel Treadmill Protocol.

Stage	Speed (mph)	Grade (%)
1	5.0	1.5
2	6.0	1.5
3	7.0	1.5
4	8.0	1.5
5	9.0	1.5
6	9.0	10
7	9.0	12.5
8	9.0	15
9	9.0	17.5

Note: Each stage is 2 minutes in duration.

During the first session, participants completed the health screening questionnaire and informed consent. After consent was attained, height was measured to the nearest 0.5 centimeters using a stadiometer (Seca, Hamburg, Germany), while mass was recorded to the nearest 0.1 kilograms using a digital scale (Detecto DR 400, Webb City, MO). After body anthropometrics were recorded, the participant's testing order was randomized to minimize risk of an order-effect bias. The Borg RPE scale (5) and request to perform the test to volitional exhaustion was thoroughly explained prior to the graded exercise test.

All VO_{2max} trials were conducted using a Trackmaster TMX425C treadmill (Full Vision, Inc., Newton, KS, USA). VO_{2max}, VE, and RER were captured via breath-by-breath, open circuit spirometry (Parvo Medics, Sandy, UT, USA). Gas exchange data were analyzed using a 15 breath moving average sampling interval (21, 25). Data were analyzed after removing any artifact from swallowing, half-breaths, or overestimations in gas exchange. Presence of a VO_2 plateau was determined by taking the closest 15 breath average and subtracting it from the largest 15 breath average, otherwise known as the VO_{2peak}. Based on previous recommendations (3, 21, 25), a VO_2 plateau was identified if the difference between the two points described above was $\leq$ 50 $mL \cdot min^{-1}$ ($\Delta VO_2 \leq 50$ $mL \cdot min^{-1}$ at VO_{2max}).

Participants were fitted with a nose clip and headgear, allowing them to breathe through a one-way valve (Hans Rudolph 2700 breathing valve, Kansas City, MO, USA). Prior to each trial, calibrations to the flowmeter and gas analyzer were performed according to manufacturer's

standards. Participants were also fitted with a heart rate monitor (Polar T31, 1Hz, Polar Oy, Kempele, Finland), that provided continuous monitoring via telemetry connection to the system. RPE was assessed using the Borg 6-20 scale during the last 15 seconds of each stage and immediately after participant termination. All data were collected in the Exercise Physiology lab.

The VO_{2max} attainment criteria used in this study included 1) VO_2 Plateau: $\Delta VO_2 \leq 50$ ml/min at test termination; 2) highest attained RER (RER_{max}) ≥ 1.10; 3) heart rate max (HR_{max}) within 10 beats·min^{-1} of age-predicted maximal HR (220 - age); and 4) final RPE ≥ 18 (2, 3, 25). Any combination satisfying two of the four criteria had to be met for the test to be consider a VO_{2max}. Otherwise, the highest VO_2 from the maximal test was considered a VO_{2peak}. Participants were asked to continue the assigned treadmill protocol until they reached volitional exhaustion, avoiding the use of handrails, while being provided with verbal encouragement. All participants remained in the analysis regardless of whether they achieved a true VO_{2max} or just a VO_{2peak} for the test.

After completion of VO_{2max} trials, participants returned to the lab for body composition assessment via air displacement plethysmography in the BodPod™ (Cosmed USA Inc.) and via circumferences using a flexible tape with attached tensiometer. Participants were asked to refrain from strenuous exercise and food at least 2 hours prior to the test, while drinking water was permitted. Participants wore form-fitting clothing, a swim cap, and removed all glasses and jewelry. Thoracic lung volume was estimated based on body weight and volume. The Siri formula (23) was used to estimate body fat percentage from the body density results of the test. All testing and calibration procedures were performed according to manufacturer's standards.

Additional anthropometric methods included circumference measurements. Two circumference measurements of the waist and hips were recorded to assess waist-to-hip ratios (WHR) for each participant. ACSM standardized sites were used for waist and hip circumferences (1). If the two measurements for each site were not within 5 mm, a third measurement was taken and the average for the two measurements was used in WHR calculations.

Statistical Analysis

An a priori power analysis revealed that 15 subjects were needed to detect an effect size of r = 0.6 given an $\alpha = 0.05$ and 1- $\beta = 0.8$ (8). While previous literature has shown that the correlation between VO_{2max} from different maximal protocols is large (r = 0.78-.93), the current study chose to be more conservative and chose an effect size of r = 0.6 (10, 12, 14).

All statistical analyses were performed using SPSS (version 26, IBM Corp). Dependent variables examined during analyses included VO_{2max}, maximum ventilation (VE_{max}), RER_{max}, HR_{max}, final RPE, and time to exhaustion (TTE). Dependent samples t-tests, comparing the novel protocol to the Bruce and Astrand individually, were used to explore differences in VO_{2max} and TTE. To correct for type 1 error inflation due to multiple comparisons, p-values were adjusted using the Bonferroni correction factor.

McNemar's Test was used to assess if there was a difference in the proportion of individuals achieving previously outlined criteria between novel and criterion protocols for the following variables: VO_2 Plateau, RER_{max}, HR_{max}, and final RPE. These continuous variables were coded into dichotomous categorical variables (yes and no) to determine whether or not maximal criteria had been reached.

Agreement analyses between Novel and Criterion protocol VO_{2max} values included Lin's concordance coefficient, mean absolute percent error (MAPE), and Bland-Altman plots. Lin's concordance coefficient was chosen because it measures agreement between two methods measuring the same continuous variable. The following criteria were used to assess agreement for Lin's concordance coefficient: > 0.99 almost perfect, 0.95-0.99 substantial, 0.90-0.95 moderate, and < 0.90 poor (17). MAPE represents the error percentage of the overall mean between measures. MAPE does not have a standardized threshold for determination of accuracy/validity of measurements. However, Fokkema et al. (9) suggest a MAPE threshold of < 5%, whereas Nelson et al. (20) used a MAPE threshold of < 10% to classify a wearable device as valid. The < 10% MAPE value was used in the present study as the criterion measure for validity. Bland-Altman analyses were carried out to determine degree of bias and 95% limits of agreement between novel and criterion measures of VO_{2max}. The differences between the Novel and Criterion measures were plotted along the Y axis against the averages of these two measures plotted along the X axis. The mean difference and standard deviation of the differences ($SD_{difference}$) were used to define the upper and lower 95% limits of agreement (mean difference ± 1.96 * $SD_{difference}$) (11). Data are represented as mean ± standard deviation unless otherwise specified.

RESULTS

Mean values for VO_{2max}, VE_{max}, and maximal attainment criteria are presented in Table 3. VE_{max} was not significantly different between any of the protocols. Additionally, VO_{2max} was not different between the Novel and Bruce (p = 0.092) protocols or the Novel and Astrand (p = 0.220) protocols. The Novel protocol displayed substantial agreement with the Bruce (r(c) = .962) and Astrand protocols (r(c) = .953). Additionally, MAPE was less than 10%, indicating that the Novel protocol is a valid measurement for VO_{2max} values (Table 4).

Table 3. Mean values for VO_{2max}, VE_{max}, and maximal criteria between Novel and Criterion protocols.

Maximal Criteria	Novel	Bruce	Astrand
VO_{2max} (mL · kg^{-1} · min^{-1})	49.40 ± 6.19	48.58 ± 6.61	49.55 ± 5.57
VE_{max} (L · min^{-1})	130.66 ± 20.16	129.45 ± 23.75	130.67 ± 20.57
VO_2 Plateau (≤ 50 mL· min^{-1})	50.27 ± 43.90	40.32 ± 30.66	35.66 ± 40.00
RER_{max} (≥ 1.10)	1.14 ± 0.06	1.20 ± 0.07	1.13 ± 0.06
HR_{max} (± 10 bpm)	193.76 ± 7.59	190.9 ± 9.30	196.04 ± 7.30
Final RPE (≥ 18)	19 ± 1.16	19 ± 1.30	19 ± 0.93
# of Participants that achieved Attainment Criteria	13	14	15

Note: Values are presented as mean ± standard deviation.

Table 4. Measures of Agreement for VO_{2max} between Novel and Criterion Protocols.

	Mean Difference ± SD	Cohen's *D*	CCC (95%CI)	MAPE (%)
Novel vs Bruce	0.86 ± 1.52	.567	.962 (.894-.986)	2.9
Novel vs Astrand	-0.15 ± 1.80	-.085	.953 (.875-.983)	2.8

Bland-Altman analysis of VO_{2max} revealed that the Novel protocol exhibited a low degree of bias with tight limits of agreement when compared to the Bruce (mean bias ±95% LOA = 0.824 ± 3.163) and Astrand protocols (mean bias ±95% LOA = -0.153 ± 3.528) (Figures 1 and 2).

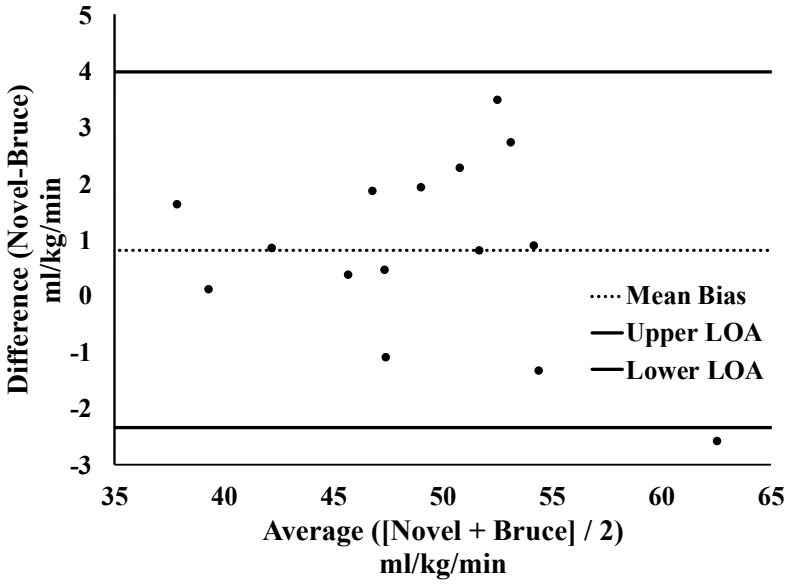

Figure 1. Agreement between Novel and Bruce protocols for VO_{2max}.

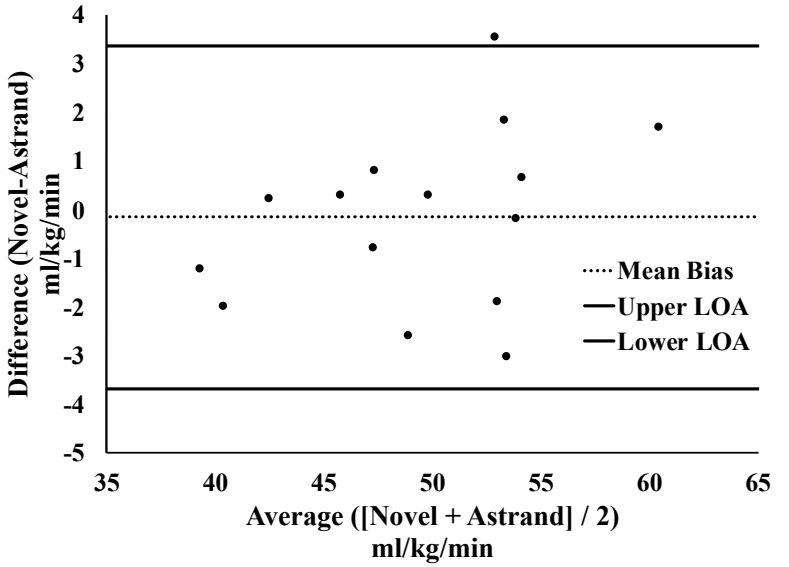

Figure 2. Agreement between Novel and Astrand protocols for VO_{2max}.

Dependent samples *t*-test revealed a significant difference in TTE between Novel (9.46 ± 1.72) and Bruce (12.07 ± 1.62) protocols ($p \leq 0.001$). Additionally, TTE was significantly lower in the Novel protocol when compared to the Astrand protocol (11.55 ± 2.39) ($p \leq 0.001$). Using the Novel protocol resulted in TTE values that were approximately two minutes shorter than either the Bruce or Novel protocols. McNemar's Test found no significant differences in the proportion of individuals achieving maximal criteria between the Novel and criterion protocols (Table 5).

Table 5. McNemar's Test for attainment of maximal criteria between Novel and Criterion protocols (n = 15).

Maximal Criteria		Bruce		Sig. (2-tailed)	Astrand		Sig. (2-tailed)
VO_2 Plateau (≤ 50 mL· min^{-1})		No	Yes		No	Yes	
Novel	No	2	5	.727	7	0	1.000
	Yes	3	5		1	7	
RER_{max} (≥ 1.10)		No	Yes		No	Yes	
Novel	No	1	1	1.000	2	0	.250
	Yes	0	13		3	10	
HR_{max} (± 10 bpm)		No	Yes		No	Yes	
Novel	No	4	0	1.000	2	2	.500
	Yes	1	10		0	11	
Final RPE (≥ 18)		No	Yes		No	Yes	
Novel	No	2	2	1.000	1	3	.250
	Yes	2	9		0	11	

DISCUSSION

The purpose of this study was to validate a Novel VO_{2max} protocol designed to be better suited for healthy populations. To the authors' knowledge, the Novel protocol used in this study is the first combinational protocol of its kind. Results indicated the Novel protocol produced similar VO_{2max} values as the Bruce and Astrand protocols. The minimal difference in VO_{2max} when compared to the Bruce protocol has also been observed by other investigators using incremental speed then grade protocols (12, 18). From these results, it appears that the Novel protocol produces valid measurements of VO_{2max} when compared to criterion methods. In agreement with previous studies, it appears that VO_{2max} is independent of treadmill protocol as long as the cardiovascular system is maximally stressed and the participant does not terminate the test due to lower extremity fatigue (9). The same VO_{2max} findings suggest that the Novel protocol is equally effective in determining an individual's cardiorespiratory fitness.

In agreement with Hamlin et al. (12), the current study observed no difference in VE_{max} between the Novel (130.66 ± 20.16), Bruce (129.45 ± 23.75), or Astrand (130.67 ± 20.57) protocols. In contrast, Miller et al. (18) observed lower VE_{max} values from their combinational protocol when compared to the Bruce protocol. It was suggested that the higher VE_{max} in the Bruce protocol was the result of more intense inclines, leading to greater localized metabolic acidosis. This produced a need for greater ventilation in order to buffer H^+ and lactate and expel CO_2 from the body. However, it is important to note that many of the participants in the current study never

reached the portion of the Novel protocol where grade increased (10%), thus exercising at the low grade (1.5%) until volitional fatigue. Therefore, the results from this study contradict the assumptions made by Miller et al. (18), because VE_{max} was the same between Novel and Bruce protocols regardless of whether or not participants reached the grade increase (10%) in the Novel protocol.

TTE was lower for the Novel (9:28) protocol when compared to the Bruce (12:04) and Astrand (11:33) assessments. In contrast, the combinational protocol used by Hamlin et al. (12) produced similar TTE as the Bruce protocol (10:18 vs 10:41). It appears that TTE and VO_{2max} are not dependent upon one another, meaning the Novel protocol was capable of providing valid VO_{2max} values in significantly less time. The current findings corroborate the stance by Kirkeberg et al. (16), that the protocol duration fails to impact VO_{2max} values when less than twelve minutes.

While the Novel protocol was designed to expose participants to changes in speed and grade, approximately half of the participants (8 out of 15) did not reach the point in the assessment wherein grade increases (10-minute mark). However, not reaching the incremental grade stages had no impact on the ability of the Novel protocol to produce almost identical VO_{2max} and VE_{max} values to that of the criterion protocols. Future investigations may consider recruiting individuals with higher cardiorespiratory fitness levels who would need to utilize the second portion of the Novel protocol where incline begins to increase. This would help determine the efficacy of the entirety of the protocol rather than just the first five stages.

Self-paced protocols with a time cap at ten minutes also provide support for more time efficient protocols. Hanson et al. (13) observed a time-capped (10 min), self-paced protocol produce almost identical VO_{2max} values as the Bruce protocol (13:17 min). In addition, extending a protocol beyond twelve minutes may introduce the opportunity to underestimate VO_{2max} in moderately trained college aged participants. A previous study by Astorino et al. (2) demonstrated that longer duration protocols (~ 13 min) lead to lower oxygen uptake values than short (~ 7 min) or moderate (~ 10 min) duration protocols. The authors suggest that the longer durations allow for greater increases in core temperature, causing enhanced peripheral vasodilation to expel the heat. With blood shunted to the periphery, less blood volume is available centrally resulting in lower venous return and stroke volume (2). Although the longer durations of the Bruce and Astrand protocols did not significantly impact VO_{2max} performance in this study, the Novel protocol may be valuable if it can consistently produce a valid measurement in a more time efficient manner with less risk of VO_{2max} underestimation.

To confirm attainment of VO_{2max}, this study utilized a stringent VO_2 plateau criteria ($\Delta VO_2 \leq 50$ $mL \cdot min^{-1}$ at VO_{2max}), based on recommendations for a 15 breath moving average sampling interval (3, 21, 25). In the present study, the Novel protocol did not significantly impact participants' ability to achieve a VO_2 plateau when compared to both the Bruce (8 vs. 10) and Astrand (8 vs. 7). Many studies still implement the most common plateau criteria of ≤ 150 $mL \cdot min^{-1}$ (or ≤ 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$) developed by Taylor et al. (24). However, it is important to

understand this plateau was established from multiday, discontinuous treadmill testing. Taylor et al. (24) derived this criterion by declaring that a change in VO_2 of < 50% of their protocol's stage increment VO_2 demand (4.23 mL · kg^{-1} · min^{-1}) signified a plateau. Therefore, this popular criterion may not represent a plateau in other protocols using different stage increments and smaller sampling rates (21). When using strict sampling rates, a plateau criteria of ≤ 50 mL·min^{-1} lead to the most accurate recognition of a VO_2 plateau (25). If the less strict plateau of ≤ 150 mL·min^{-1} had been the adopted in the current study, it would have led to an overestimation in the achievement of a VO_2 plateau (3, 21). Using a strict plateau criterion allows this study to confidently assume participants who exhibited a plateau achieved their true VO_{2max} and not just a VO_{2peak}.

Attainment of secondary criteria (RER_{max}, HR_{max}, final RPE) was not significantly different following the Novel protocol when compared to the criterion protocols. Previous studies by Hamlin et al. (12) and Miller et al. (18) observed significant differences in RER_{max} and HR_{max} between combinational protocols and the Bruce protocol. However, it should be noted that the authors analyzed these variables on a continuous level of measure whereas the application of these cutoff measures is moreso dichotomous (i.e., achieved/did not achieve). Therefore, it is possible to detect differences in raw values between each protocol while similar proportions of individuals surpassed the criterion score for a given variable. For example, the mean RER_{max} observed by Miller et al. (18) for their combinational protocol (1.2 ± 0.1) and Bruce protocol (1.3 ± 0.1) eclipsed the maximal criteria used in the current study (≥ 1.10). Additionally, using the mean age (23.2 ± 5.4) from the study, both the combinational and Bruce protocol achieved mean HR_{max} values that were within ± 10 beats of an estimated age-predicted maximal HR for their participants (187 to 207 bpm) (Comb: 192 ± 9.9 vs Bruce: 188 ± 9.3). Lastly, final RPE was not significantly different between the protocols utilized by Miller et al. (18) with both protocols achieving maximal criteria for final RPE final (≥ 18) in the current study (Comb: 18.9 ± 1.5 vs Bruce: 18.3 ± 1.1).

Any novel investigation is exposed to opportunity for improvement. The current investigation would have been strengthened by more participants completing the advanced portion of the protocol so that a more holistic validation could take place. The sample was very homogenous in age; future investigations may consider expanding the age limit to evaluate the Novel protocol in other generations. A little fewer than half of the participants in the study failed to achieve a VO_2 plateau (< 50 ml/min). Fortunately, many agree that secondary measures (RER, RPE, HRmax) are telling of maximal effort when plateau is not achieved.

In conclusion, the Novel protocol used in this study can be used interchangeably with the criterion protocols to produce valid VO_{2max} performances, agreeing that VO_{2max} was independent of the protocol selected. A secondary finding was that the Novel protocol was completed in less time than the other two criterion protocols. Future studies and extensive testing will be needed to further validate the Novel protocol. It may be beneficial to classify the fitness level of each participant as this will allow for the treadmill speeds of the Novel protocol to be tailored to the fitness level of the participant. Still, the Novel protocol provides

practitioners with a more time efficient test that will produce valid results. All treadmill protocols were equally effective at achieving the maximal criteria for VO_2 plateau, RER_{max}, HR_{max}, and final RPE. Lastly, the obtainment of maximal criteria for RER_{max}, HR_{max}, and final RPE appears to be much more reliant on the participant rather than the selection of the Novel or criterion protocols used in this study.

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