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Original Research

Validation of a New Ramping Aerobic Exercise Protocol (NDKS) in Overweight, Obese, and Normal Weight Individuals

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ABSTRACT

International Journal of Exercise Science 15(4): 386-398, 2022. The research purpose was to establish reliability and validity of determining VO_{2max} via a new NDKS (Nustad Dressler Kobes Saghiv; named for the sir names of department faculty at the time) ramping protocol compared to the Standard Bruce protocol in normal weight, overweight, and obese individuals. Forty-two physically active participants (23M, 19F) ages 18-28 years were grouped into normal weight (N = 15, 8F, BMI 18.5-24.9 kg/m^2), overweight (N = 27, 11F, BMI = 25-29.9 kg/m^2), and Class I obese (N = 7, 1F, BMI = 30-34.9 kg/m^2). Blood pressure, heart rate, blood lactate, respiratory exchange ratio, test duration, rate of perceived exertion, and preference via survey were analyzed during each test. Test-retest reliability of the NDKS was determined first, via tests scheduled one week apart. The NDKS was then validated by comparison with results of the Standard Bruce protocol; tests also conducted one week apart. The normal weight group's Cronbach's Alpha was .995 for absolute VO_{2max} (L/min) and .968 for relative VO_{2max} (mL/kg·min). Overweight/obese Cronbach's Alpha for absolute VO_{2max} (L/min) was .960 and for relative VO_{2max} (mL/kg·min) .908. Relative VO_{2max} was slightly higher with NDKS and test time lower compared to the Bruce (p < .05). 92.3% of subjects identified more localized muscle fatigue with the Bruce protocol vs NDKS. The NDKS is a reliable and valid exercise test which can be used to determine VO_{2max} in physically active, young normal weight, overweight and obese individuals.

KEY WORDS: Aerobic functional capacity, reliability, validity, ramped treadmill

INTRODUCTION

The Standard Bruce (Bruce) is a validated (3) treadmill protocol commonly used in hospital and research laboratory settings for graded exercise testing (GXT), assessing human responses to exercise and when combined with indirect calorimetry, used to obtain assessment of maximal oxygen consumption (VO_{2max}). While validated, the Bruce has relatively large incremental workload increases per every 3-minute stage (3-4 METs) with significant incline (i.e. initial grade

of 10% with 2% increases every stage), where local muscle fatigue may lead to early test-end (16) and/or workload associated with one's true VO_{2max} may lie between graded increments.

Ramping exercise protocols are a valid alternative to assess aerobic fitness (1, 11, 16, 20) with more gradual increases in workload, offering the possibility of reduced severity of local muscle fatigue (16) and better identify specific workloads at which ischemic changes occur (14). Ramping protocols provide a more consistent linear increase in work rates and oxygen uptake, thus may obtain a more specific peak workload, especially helpful if estimating VO_{2max} based on workload and not direct or indirect spirometry (1). Other researchers have produced ramping protocols that match speed and grade of the Bruce stages every 3-minute time interval (8, 20). These protocols accommodate clinical needs for comparing hemodynamic responses between Bruce and Ramp Bruce tests with more gradual increases in workload, but still have the high incline levels contributing to premature local muscle fatigue. In obese individuals, Ramped Bruce outcomes were found to be more consistent compared to Standard Bruce in terms of functional capacity and METs achieved (1). Overweight and obese populations have not shown significant differences between ramp and graded protocols in hemodynamic responses in comparison to normal weight individuals (11). Bires et al. reported neither protocol was superior to the other for the examination of VO_{2max} in patients with BMI ≥ 30 kg/m (1). However, ramped protocols have been found less physically and mentally imposing in patient and nonpatient populations (1, 16, 20) where some researchers have shown obese individuals preferred a ramping protocol due to its comfort and smaller workload increases (20).

The present study proposed to establish reliability and validity of determining VO_{2max} via a new NDKS (Nustad Dressler Kobes Saghiv; sir names of colleagues from the University of Mary Exercise Physiology Lab) ramping protocol that matches MET demand with the Bruce at each 3-minute interval, but with lower incline compared to the Bruce, in normal weight, overweight, and obese individuals. Furthermore, subjective tolerance assessments were included.

METHODS

This study was approved by the University of Mary Institutional Review Board, University of Mary, Bismarck, ND. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (12).

Participants

Physically active normal weight, overweight, and obese males and females ages 18-28 years were recruited to participate in this study. Subjects were excluded if they were not able to walk/run on a treadmill and if they had known cardiac, metabolic, or kidney disease, or signs or symptoms thereof. Physically active was determined according to criteria defined by the American College of Sports Medicine (6).

Protocol

A mixed methods crossover design was used with quantitative and qualitative outcomes. Subjects completed 2 or 3 maximal exercise tests conducted one week apart; some did two NDKS

protocols (reliability study), some did one NDKS and one Standard Bruce (validity study), and some did two NDKS and a Bruce (participating in both reliability and validity arms of the study). Reliability was established first, determined by comparing results of two tests using the NDKS ramping protocol, conducted one week apart. Then, validity was determined by comparing NDKS VO_{2max} to results of the previously validated Standard Bruce protocol (3), also conducted one week apart. For participants who participated in both the reliability and validity arms of the study, the mean NDKS data was used to compare with the Standard Bruce, where the second NDKS test was completed one week prior to the Bruce. All tests were conducted on a calibrated treadmill (SportsArt Fitness Model 6320 HR). The order of Bruce and NDKS was assigned, such that about half the group did Bruce first and half did NDKS first. All participants who did both reliability and validity arms of the study did the NDKS first.

A 5-question survey written by the research team and critiqued by a member of the University of Mary psychology department was implemented following completion of both tests. Subjects were instructed to choose one of three options for each question: 1) NDKS 2) Bruce 3) no preference/same. The survey asked which test they would prefer to do if they needed to do one again; which caused more anxiety; which caused more localized muscle fatigue; which protocol they felt they performed better on; and which protocol they felt most comfortable doing at their current fitness level. Subjects were blinded to their VO_{2max} results to avoid biased opinions towards each test. About half the subjects completed the survey following the Bruce as their last test protocol and the other half following the NDKS as their last test protocol. Answers were evaluated based on a frequency count of subjects' perceived comparisons.

During the first data collection session, procedures were explained, and subjects completed informed consent, health history questionnaire (HHQ), and pretest instruction forms. Subjects were familiarized with the treadmill and Hans Rudolph face mask (fitted for the appropriate size mask and walked on the treadmill while wearing the mask for 5 minutes). Baseline measures including heart rate (bpm) (Polar F1 Heart Rate Monitor), blood pressure (mmHg) (standard mercury sphygmomanometer), blood lactate (mmol/L) (fingertip Point of Care (POC) lactate meter, NOVA Biomedical Lactate Plus analyzer), height (cm) (calibrated stadiometer), and weight (kg) (digital scale ADAM CPWplus-200) were measured and recorded. Subjects were then scheduled for their tests, one week apart at approximately the same time of day.

At each subsequent testing visit, subjects were asked if they adhered to pretest instructions (drink plenty of water over the 24-hour period preceding the test, avoid tobacco, alcohol, and caffeine for at least 3-hours before the test, avoid a heavy meal within 4 hours of the test, avoid strenuous physical activity 24-hours prior to the test, get adequate sleep (6-8 hours) the night before the test), height, weight, and resting blood lactate (LA), blood pressure (BP), and heart rate (HR) were reassessed to account for any fluctuation, using the same equipment described above, with BP and HR in both sitting and standing positions. During each maximal exercise test exercise blood pressure (BP), heart rate (HR) (POLAR F1 HR monitors), rating of perceived exertion (RPE) (Borg's Original 6-20 Scale) (2, 18, 21), oxygen consumption (VO_2) (L/min and mL/kg·min) (Parvo Medics TrueOne 2400 Metabolic System), and respiratory exchange ratio (RER) were monitored and recorded. HR, RER, and VO_2 were measured every minute

throughout the test and BP was measured every other minute during the NDKS and during the last minute of every 3-minute stage of the Bruce. RPE was asked every other minute until later in the test, when it was asked more frequently and obtained at peak effort. Immediately after (within a minute post) completion of the test, peak BP and post blood lactate were measured. Subjects were then provided 5 minutes of active recovery, walking on the treadmill and monitored in passive recovery, being allowed to leave upon return to near baseline and asymptomatic.

NDKS Protocol: is a ramping maximal treadmill protocol that increases either speed or grade every minute and is performed to exhaustion. Subjects were given a 2-5-minute warm up period before starting the test, at a speed of 2.3 mph and 0% grade. The test started at a 5% incline and was increased 1% every other minute. Speeds started at 3.1 and progressively moved up to 3.7, 4.3, 5.0, and 5.6 mph every other minute, opposite the increases in %grade; full protocol depicted in Table 1. *Bruce Protocol*: is a commonly used validated graded exercise test with 3-minutes stages (3). VO_{2max} with both protocols was determined if subjects met three out of five of the following criteria: RER ≥ 1.1, maximal heart rate ± 10 bpm of age predicted heart rate max (220-age), RPE > 17, post blood lactate ≥ 8 mmol/L, and plateau of VO_2 as determined by VO_2 change < 0.15 L/min with increase in workload (6). Subjects' warm up was 2-5 minutes for both tests, determined by stability of VO_2, HR, and RER and subjects' indicating readiness to proceed.

Table 1a. NDKS Protocol

Time (min)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13
Speed (mph)	3.1	3.7	3.7	4.3	4.3	5.0	5.0	5.6	5.6	6.2	6.2	6.8	6.8
Grade (%)	5	5	6	6	7	7	8	8	9	9	10	10	11
METs	5.5	6.4	6.9	7.9	8.4	11.1	11.4	12.7	13.	14.3	14.8	16.1	16.6

Table 1b. NDKS Protocol continued

Time (min)	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
Speed (mph)	7.4	7.4	8.0	8.0	8.6	8.6	9.2	9.2	9.8	9.8	10.4
Grade (%)	11	12	12	13	13	14	14	15	15	16	16
METs	17.9	18.5	19.9	20.4	21.9	22.5	23.9	24.6	26.1	26.8	28.34

Respiratory analyses were determined using oxygen and carbon dioxide analyzers (Parvo Medics TrueOne 2400 Metabolic System), indirect calorimetry, while participants wore a Hans-Rudolph Mask with one-way breathing valves. VO_2 was measured via an expiratory pneumotachometer. A combination of expired gas analysis and ventilation measures were used to determine VO_2, VCO_2, and RER and were continuously monitored throughout the exercise test. The highest 30 second average of VO_2 was used as the measurement of VO_{2max}.

Statistical Analysis

Statistical analysis was done using SPSS 26 for Windows. Descriptive statistics are reported as Mean ± SE. One-way ANOVA was used to compare normal, overweight, and obese baseline characteristics. NDKS test-retest reliability analysis was completed as Cronbach's Alpha. Paired *T* tests were conducted to compare normal to the overweight/obese combined group for both reliability and validity arms of the study ($\alpha = 0.05$). Between protocol differences in VO_{2max}

relative and absolute, HR_{max}, blood lactate, RER, RPE, and time it took to reach max were determined by Paired *T*-test ($p \leq 0.05$). Survey data was analyzed using a simple frequency of responses comparison.

RESULTS

Reliability: Forty-two physically active adults aged 18-28 years (23M/19F; 21.98 ± .077 yrs) were recruited for the reliability study. Participants were grouped according to BMI, into normal weight (BMI 18.5-24.9 kg/m²; *N* = 15, 8F), overweight (BMI = 25-29.9 kg/m²; *N* = 20, 10F), and obese Class I (BMI = 30-34.9 kg/m²; *N* = 7, 1F). See Table 2 for subject baseline characteristics. Resting systolic blood pressure was statistically greater in the overweight females compared to normal weight females (p = .008; point estimate range .23 to .45). There were no significant differences between overweight and obese groups for men or women other than BMI (Males: p < .001; point estimate range .81 to .91)(Females: p < .001; point estimate range .55 to .75). Thus, overweight and Obese Class I subjects were combined into one group (*N* = 27; 16 M and 11 F) for reliability analysis.

Table 2. Resting Baseline Characteristics (Mean ± SE)

Variable	Normal Weight BMI = 18.5-24.9 kg/m²			Overweight BMI = 25-29.9 kg/m²			Obese Class I BMI = 30-34.9 kg/m²		
	Total (*N* = 15)	Male (*N* = 7)	Female (*N* = 8)	Total (*N* = 20)	Male (*N* = 10)	Female (*N* = 10)	Total (*N* = 7)	Male (*N* = 6)	Female (*N* = 1)
Age (years)	21.20 ± .405	21.57 ± .612	20.88 ± .549	22.40 ± .600	22.80 ± .712	22.00 ± .989	22.43 ± .565	22.17 ± .307	24.00
BMI (kg/m²)	*22.91 ± .304	22.58 ± .405	23.21 ± .444	*27.25 ± .309	27.73 ± .429	26.76 ± .408	*32.06 ± .565	32.38 ± .554	30.16
HR (bpm)	73.47 ± 3.79	69.71 ± 5.626	76.75 ± 5.191	68.10 ± 2.966	64.50 ± 4.435	71.70 ± 3.821	65.286 ± 2.327	64.83 ± 2.701	68.00
SBP (mmHg)	110.00 ± 1.789	114.00 ± 2.795	106.5 ± 1.547	115.10 ± 1.906	117.80 ± 2.795	*112.4 ± 1.024	114.85 ± 4.490	116.68 ± 4.863	104.00
DBP (mmHg)	68.53 ± 1.856	69.71 ± 3.476	67.50 ± 1.880	71.80 ± 1.142	73.80 ± 1.348	69.80 ± 1.672	73.71 ± 4.241	76.00 ± 4.227	60.00
Lactate (mmol/L)	2.09 ± .332	1.91 ± .450	2.24 ± .504	2.08 ± .216	2.17 ± .275	2.00 ± .345	3.18 ± .803	3.66 ± .791	.80

*p < .05

Fifteen normal weight (8F) and 27 overweight/obese subjects (11F) completed the reliability trials consisting of two NDKS tests, conducted one week apart at approximately the same time of day. All subjects reported adherence to pre-test instructions. One normal weight female subject was removed from the VO_{2max} analysis due to faulty gas analysis in trial 2. Otherwise, criteria met maximal effort and therefore the subject's data was included in analysis of other test variables. Males and females combined, the normal weight group's Cronbach's Alpha was .995 for absolute VO_{2max} (L/min) and .968 for relative VO_{2max} (mL/kg·min). Overweight/obese Cronbach's Alpha for absolute VO_{2max} (L/min) was .960 and for relative VO_{2max} (mL/kg·min) .908. There were no significant differences between physiological responses in first and second NDKS tests in normal weight (Table 3) or overweight/obese groups (Table 4). Test-retest

reliability for absolute and relative VO_{2max} with combined BMI groups demonstrates a strong positive relationship (Figures 1 and 2).

Table 3. Reliability NDKS 1 vs NDKS 2, Normal Weight BMI Classification; Mean ± SE

	Normal Weight – BMI = 18.5-24.9 kg/m²	
Variable	NDKS 1	NDKS 2
VO_{2max} (mL·kg·min)	47.98 ± 3.268	49.17 ± 2.596
VO_{2max} (L·min)	3.392 ± .442	3.468 ± .404
HR_{max} (bpm)	187.7 ± 4.46	190.3 ± 2.79
Lactate $_{immediate\ post}$ (mmol/L)	12.53 ± .87	12.50 ± 1.01
RPE max	19.00 ± .447	19.17 ± .477
RER max (VCO_2/VO_2)	1.15 ± .023	1.16 ± .019
Test Time (minutes)	10.00 ± .824	10.36 ± .720

** Denotes significant difference between trials ($p < .05$.)*

Table 4. Reliability NDKS 1 vs NDKS 2, Overweight/Class I Obesity BMI Classification; Mean ± SE

	Overweight/Class I Obesity BMI = 25-34.9 kg/m²	
Variable	NDKS 1	NDKS 2
VO_{2max} (mL·kg·min)	44.41 ± 1.908	45.27 ± 1.912
VO_{2max} (L·min)	3.61 ± .265	3.691 ± .281
HR_{max} (bpm)	186.9 ± 1.402	187.8 ± 1.812
Lactate $_{immediate\ post}$ (mmol/L)	11.43 ±.758	11.1 ± .817
RPE max	19.80 ± .133	19.0 ± .537
RER max (VCO_2/VO_2)	1.15 ± .008	1.18 ± .010
Test Time (minutes)	9.15 ± .420	9.33 ± .444

** Denotes significant difference between trials ($p < .05$.)*

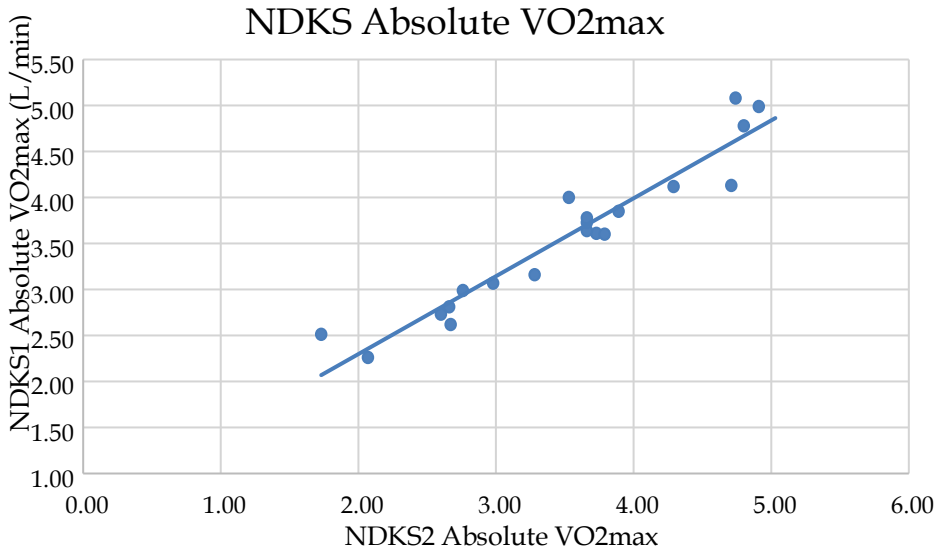

Figure 1. Relationship between mean absolute VO_{2max} NDKS 1 and NDKS 2 tests, all BMI groups combined (N = 41, 18F, 23M).

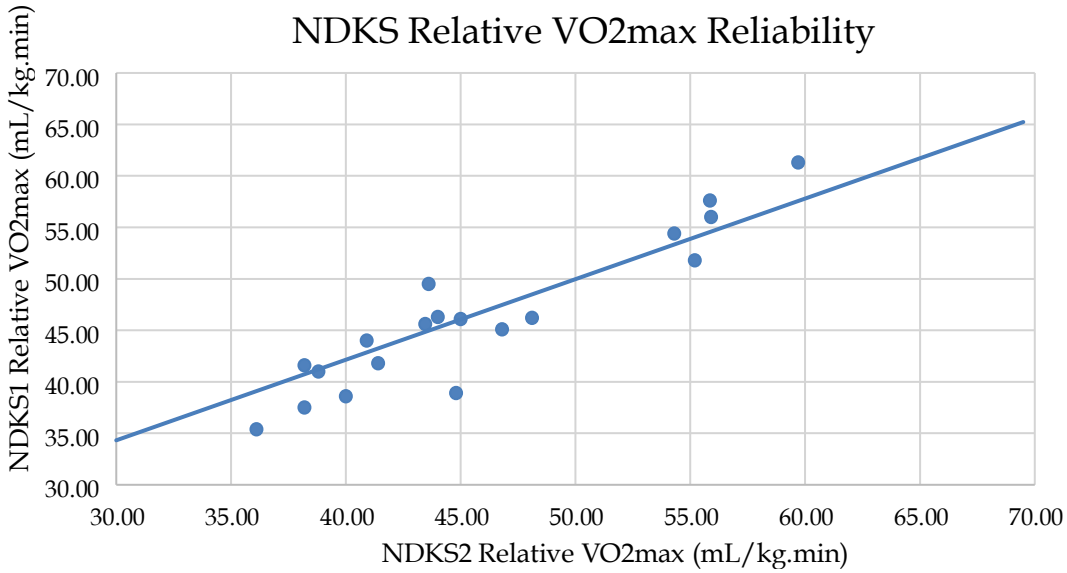

Figure 2. Relationship between mean relative VO_{2max} NDKS 1 and NDKS 2 tests, all BMI groups combined (N = 41, 18F, 23M).

Validity: 40/16F subjects participated in the validation arm of the study, completing the NDKS and Bruce protocols. One subject's data was removed from analysis due to not meeting maximal criteria for the Bruce test. For subjects who completed two NDKS tests and one Bruce test, the mean of NDKS test scores was used to compare with results from the Bruce.

With all BMI classification groups combined for analysis (N = 39, 16F), there was a strong correlation between NDKS and Bruce protocols for absolute (L/min)(r = .98)(p < 0.001; d = .31) and relative (mL/kg/min) VO_{2max} (r = .96)(p < 0.001; d = .38) (Figures 3 and 4). When normal weight and overweight, and obese groups were analyzed separately, there were statistically significant differences in absolute (L/min) and relative (mL/kg·min) VO_{2max} between the NDKS and Bruce protocols for the normal weight group and not the overweight and obese groups (Table 5). However, with all groups combined, there was a comparable yet statistically significant difference in relative VO_{2max} mL·kg·min (NDKS 46.77 ± 1.276; Bruce 45.88 ± 1.216) with a small to moderate effect size (p = .023; d = .38). HR_{max} and RER, were also clinically comparable yet statistically different between protocols with BMI groups combined (Table 4). NDKS test time was less (NDKS 10.74 ± .437; Bruce 12.18 ± .334; p < .001; d = -.67). Other maximal and immediate post responses did not differ between protocols with combined groups (Table 6).

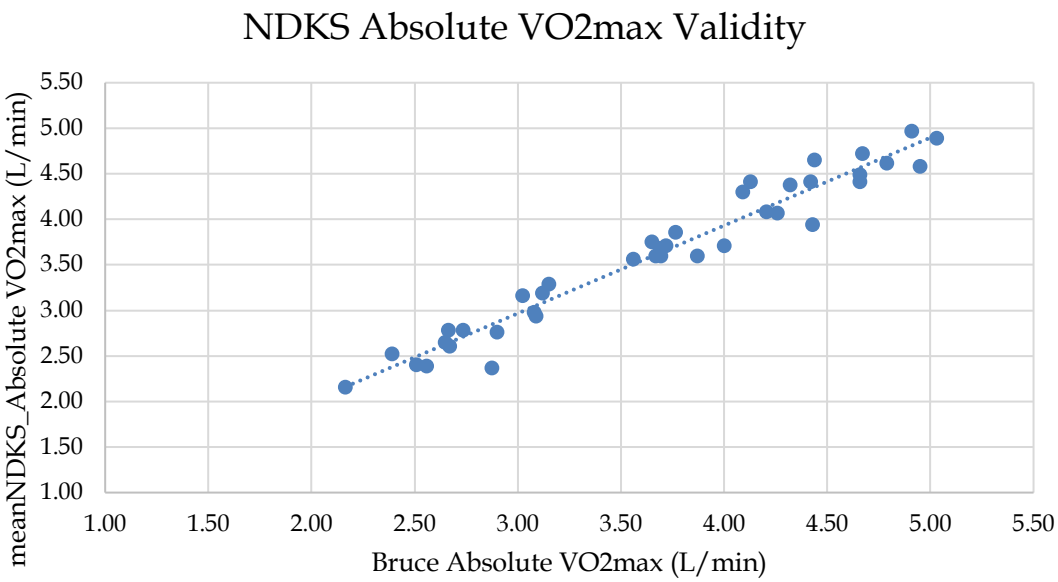

Figure 3. Relationship between mean relative VO_{2max} Mean NDKS and Bruce tests, all BMI groups combined (*N* = 39, 16F).

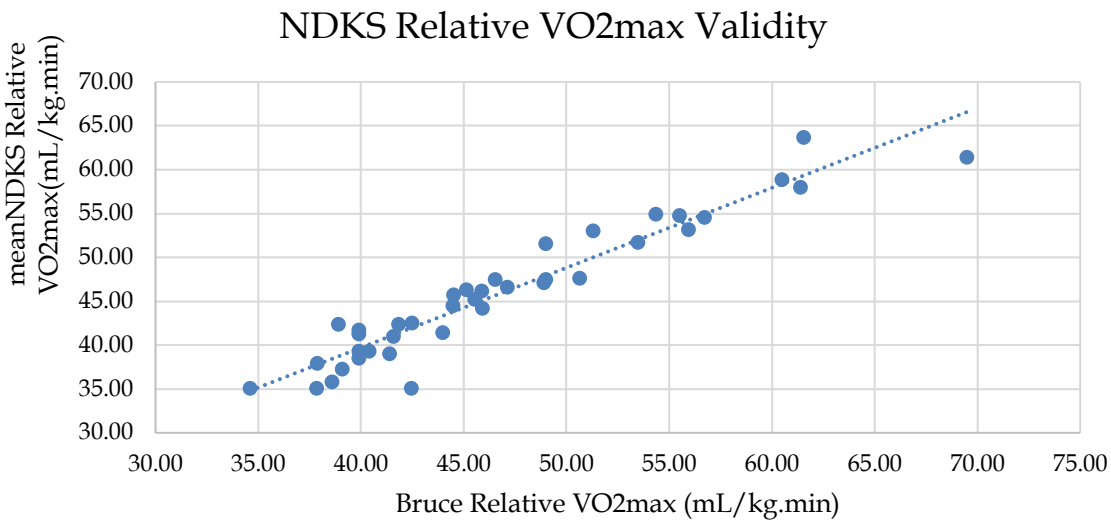

Figure 4. Relationship between mean relative VO_{2max} Mean NDKS and Bruce tests, all BMI groups combined (*N* = 39, 16F).

Table 5. Maximal NDKS and Bruce protocol validation test responses per BMI classification (Mean ± SE) NWt (*N* = 14), OvrWt (*N* = 19), Ob-1 (*N* = 6)

Variable	BMI Category	NDKS	Bruce	*P* Value	Cohen's *d*
VO_{2max} (mL·kg·min)	NWt	50.72 ± 2.587	48.86 ± 2.514	.032*	.641
	OvrWt	44.27 ± 1.214	44.37 ± 1.97	.384	.205
	Ob-1	43.34 ± 3.037	43.70 ± 3.439	.746	.140
VO_{2max} (L·min)	NW	3.53 ± .251	3.40 ± .238	.048*	.582
	OvrWt	3.58 ± .186	3.62 ± .186	.770	.068
	Ob-1	4.00 ± .179	4.09 ± .194	.653	.195
HR_{max} (bpm)	NWt	189.62 ± 2.28	190.00 ± 2.17	.869	.457
	OvrWt	188.87 ± 1.77	187.53 ± 2.10	< .006*	.747
	Ob-1	194.71 ± 1.74	193.17 ± 2.39	.093	.848
Lactate immediate post (mmol/L)	NWt	12.46 ± .78	10.53 ± .75	.056	.693
	OvrWt	10.44 ± .55	10.84 ± .54	.513	-.167
	Ob-1	10.51 ± 1.83	13.2 ± 2.11	.123	-1.063
RPE max	NWt	19.12 ± .26	19.31 ± .31	.662	-.695
	OvrWt	19.35 ± .22	19.05 ± .19	.287	.252
	Ob-1	20 ± .00	19 ± .36	.041	1.118
RER max (VCO_2/VO_2)	NWt	1.14 ± .01	1.18 ± .01	.006*	-.880
	OvrWt	1.15 ± .01	1.18 ± .01	.012 *	-.638
	Ob-1	1.15 ± .02	1.17 ± .03	.173	-.649
Test Time (minutes)	NWt	11.86 ± .79	13.26 ± .68	.056	-.545
	OvrWt	9.62 ± 11.52	11.52 ± .31	< .001*	-.967
	Ob-1	10.69 ± 1.09	11.79 ± .87	.620	-.215

* *Denotes significant difference (p < .05);* NWt = Normal Weight (*N* = 14), BMI = 18.5-24.9 kg/m²
OvrWt = Overweight (*N* = 19), BMI = 25-29.9 kg/m²; Ob-1 = Obese Class I (*N* = 6), BMI = 30-34.9 kg/m²

Table 6. Combined BMI Classification Groups NDKS vs Standard Bruce at Maximal Exercise; (Mean ± SE; *p* value; Cohen's *d*) (*N* = 39, 16F)

Variable	NDKS	Bruce	*p* Value	Cohen's *d*
VO_{2max} (mL·kg·min)	46.77 ± 1.28	45.88 ± 1.22	.023*	*d* = .38
VO_{2max} (L·min)	3.67 ± 0.13	3.62 ± 0.13	.058	*d* = .31
HR_{max} (bpm)	190.36 ± 1.26	188.81 ± 1.38	.018*	*d* = .41
Lactate $_{immediate\ post}$ (mmol/L)	11.21 ± 0.51	11.03 ± 0.52	.686	*d* = .08
RPE max	19.53 ± .14;	19.14 ± 0.17	.205	*d* = .21
RER max (VCO_2/VO_2)	1.15 ± 0.006	1.18 ± 0.008	< .001*	*d* = -.73
Test Time (minutes)	10.57 ± 0.432	12.18 ± 0.334	< .001*	*d* = -.67

* *Denotes significant difference (p < .05)*

Qualitative Survey: All subjects who completed both the NDKS and Bruce protocols (*N* = 39) also completed a subjective survey following the last test protocol they completed. Survey results are reported in Table 7, where 92.3% of subjects identified more localized muscle fatigue with the Bruce protocol.

Table 7. Survey results shown as number of responses and valid percent.

Total *N* = 39	NDKS	BRUCE	No Preference
Q1 Preference	24 (61.5%)	9 (23.1%)	6 (15.4%)
Q2 Comfort at current fitness level	23 (54.8%)	7 (17.9%)	9 (23.1%)
Q3 Localized Muscle Fatigue	3 (7.7%)	36 (92.3%)	0 (0.0%)
Q4 Anxiety	4 (9.5%)	13 (33.3%)	22 (56.4%)
Q5 Perceived Performance	24 (61.5%)	11 (28.2%)	4 (10.3%)

DISCUSSION

Chronbach's Alpha results demonstrated NDKS ramping treadmill protocol has strong test-retest reliability for absolute and relative VO_{2max} in normal weight and overweight/Class I obese physically active and otherwise healthy young males and females. Establishing test-retest reliability first, is a necessary process of determining validation of an assessment tool (17). NDKS ramping treadmill protocol was determined to be a valid test of absolute and relative VO_{2max} in this population (r = 0.98 and r = 0.96, respectively), with possibly better performance compared with the Bruce. Similar VO_{2max} (absolute and relative) values between ramping and Bruce protocols have been reported by other researchers (7, 15, 19). Ramping protocols showing no statistically significant differences in VO_{2max} outcomes supports their effectiveness for maximal exercise testing.

When comparing NDKS to Bruce protocol, maximal Respiratory Exchange Ratio (RER_{max},) blood lactate (LA imm post), heart rate (HR_{max},) and Rating of Perceived Exertion (RPE_{max}) were clinically comparable, further validating the NDKS protocol to the Bruce. Test duration to max however, was significantly and clinically shorter in the NDKS (mean difference of 1.61 minutes). The NDKS ramping protocol has linear increases in workload, lending itself to a shorter test because the slope is more extreme compared to incremental increases in workload. This may have allowed the subjects to achieve their maximal oxygen uptake more quickly. This differs from other reports on test duration, where the Bruce test time has been shorter than other ramp protocols (1, 6, 9, 11, 20).

Linear increases in ramping protocol workload compared to the Bruce have also been discussed with the BSU/Bruce Ramp protocol that used the same speed and grade per every three minutes as the Bruce GXT, but with a ramping protocol increasing speed and grade every minute (8). NDKS also matches workloads (METS) per every three minutes with the Bruce GXT protocol, but differs from the BSU/Bruce ramp protocol by achieving the matched workload via lower incline and higher speed. Thus, the NDKS addresses the issue of local muscle fatigue brought on by high incline, whereas the BSU/Bruce ramping protocol does not. This was supported by our survey data and previous reports where up to 53.1% of "relatively fit college students"

prematurely terminated the Bruce GXT due to local leg fatigue opposed to whole body fatigue (16). It could also explain the slightly greater VO_{2max} in the NDKS protocol. It is logical that protocol choice and local muscle fatigue issues could make a greater difference in functional capacity outcomes when testing physically inactive, clinical, and/or older populations vs physically active young individuals. The overweight and obese groups in our NDKS validation study did not show differences in VO_{2max} outcomes, however additional research is needed with more clinical populations.

While HR_{max} was highly correlated when controlling for BMI category ($R = .90$; $p < .001$) between protocols, it was significantly ($p < .05$) higher for the NDKS compared to the Bruce, but only 1.55 bpm difference in mean values, rendering it clinically negligible. Other researchers have found ramping protocols tend to obtain higher heart rates, ranging from four to twelve beats per minute (13, 16). $LA_{immediate\ post}$ values were not significantly different which was unexpected. Our hypothesis considered the incline of the Bruce GXT could provoke higher maximal glycogen utilization, and thus higher blood lactate when compared to the NDKS protocol. When considering the workloads (comparable METS at 3 minute intervals achieved with higher speed and lower incline) of the NDKS vs Bruce and the physically active subjects of the present study, may support comparable $LA_{immediate\ post}$ values between protocols. The workloads (METS) align per every three minutes between protocols, however at specific times between each 3-minute increment, METS are different, where NDKS workload increases while Bruce remains the same. RER_{max} responses were similar to findings of Costill et al. who reported higher RER values during the Bruce compared to ramping (5). The high incline of the Bruce GXT may cause participants to recruit type II fibers earlier, using anaerobic metabolism earlier at submaximal workloads, causing a higher energy expenditure earlier, which only increases as the subject reaches maximal workloads, like seen in most studies of uphill running, and resulting in higher RER values (9, 10).

Nearly all (92.3%) subjects reported that Bruce caused more perceived local muscle fatigue compared to the NDKS. These findings are consistent with Spackman et al. comparing ramp protocols with the Bruce (16). Overall, 65% of participants reported they would prefer to repeat the NDKS protocol vs the Bruce, which supports the idea of NDKS as a more comfortable experience. Survey questions that were different than the Spackman et al. study showed that over half of subjects reported feeling more comfortable performing the NDKS, and two-thirds of subjects reported they thought their performance was better using the NDKS protocol compared to the Bruce.

Limitations include a low to modest subject number and particularly low number of obese subjects, warranting the combination of Overweight with Class I Obesity groups for reliability analysis. Results cannot be generalized to persons with Class II and III levels of obesity, and with the small number of Class I subjects, it might be a stretch to ascertain this population vs overweight with young physically active healthy individuals. Use of Body Mass Index for classification of overweight and obese can be variable in validity and accuracy for the physically active population (4). Use of body fat percentage for physically active overweight and obese populations is recommended for future research. Lastly, it is noted that survey data has potential

for bias and muscle fatigue was not assessed directly. Local muscle fatigue was subjectively assessed via the survey questionnaire and indirectly via blood lactate. Therefore, it cannot be quantifiably determined that subjectively reported local muscle fatigue was caused by lactate concentration, increased glycogen utilization in the lower limbs, or other factors involving physiological mechanisms of local muscle fatigue.

Further research should focus on investigating use of the NDKS protocol in the evaluation of more clinical, unfit, and elderly populations. There could also be exploration into direct assessment of local muscle fatigue to confirm or deny the effect this may have on maximal performance.

In conclusion, the NDKS protocol is a reliable and valid exercise test which can be used to determine maximal oxygen consumption or VO_{2max} in young physically active, normal weight, overweight, and obese Class I male and female adults.

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