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Research article

Cardiopulmonary Exercise Testing with Elastic Resistance: A New Reproducible Proposal for Determination of Ventilatory Thresholds and Maximum Oxygen Consumption

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Abstract

To propose a new Cardiopulmonary Exercise Test with Elastic Resistance (CPxEL) and compare the physiological responses to conventional cardiopulmonary exercise test (CPx) performed on a treadmill. In addition, we tested the reproducibility of the CPxEL. Twenty-four physically active participants completed the CPx (first session) and CPxEL twice (second and third sessions) interspersed by seven days. A treadmill protocol with increments of 1km·h^{-1} every minute until exhaustion was used in CPx. The CPxEL consisted of performing alternating steps back-and-forth against an elastic resistance attached to a belt and an incremental protocol with 1 stage (S) per minute following a cadence of 200 bpm controlled by a metronome in an 8-stage rubber mat. First analysis: first ventilatory threshold (VT1) occurred at 69.7% and 75.3% of maximal heart rate (HR_{max}) and 53.5% and 65.7% of maximal oxygen consumption ($\dot{V}O_{2max}$). Second VT (VT2) occurred at 93.3% and 96.8% of the HR_{max} and 87.0% and 96.9% of $\dot{V}O_{2max}$ for CPx and CPxEL, respectively. At exhaustion, $\dot{V}O_{2max}$, perceived exertion (BORG-CR10 and OMNI-RES EB), and test duration presented lower values for CPxEL ($P < 0.05$). Second analysis: VT1 occurred at warm-up (S0) ($P = 0.731$), VT2 occurred at S5 ($P = 0.912$), and the exhaustion occurred at S6 and S7 ($P = 0.271$) for CPxEL and retest, respectively. The intraclass correlation coefficient (ICC) for $\dot{V}O_{2max}$ was 0.921 and for HR_{max} was 0.930. The CPxEL has good test-retest reproducibility and represents a possible and interesting add-on to determine maximal oxygen consumption, maximal heart rate, and second ventilatory threshold without using traditional ergometers.

Key words: Cardiopulmonary exercise test, ventilatory thresholds, exercise testing, accessibility.

Introduction

The cardiopulmonary exercise test (CPx) is a gold-standard method for $\dot{V}O_{2max}$ determination that reflects an integration of metabolic and physiological systems until volitional exhaustion (Balady et al., 2010). Also, the first and second ventilatory threshold (VT1 and VT2, respectively) can be identified and predict non-invasively the aerobic capacity, which allows monitoring and prescription of physical exercise training (Balady et al., 2010; Poole et al., 2021). A plateau of maximal oxygen consumption is defined by a work rate (or speed) of exercise that resulted in no further increase in $\dot{V}O_2$, although the increase in energy demand was established, and this plateau response was considered a true $\dot{V}O_{2max}$, as proposed by Taylor et al. (1955) (Astorino et al., 2005). It is also known that age is a strong predictor of a plateau or not (Astorino et al., 2005). Because of the high variability of $\dot{V}O_{2max}$ determination, some researchers recommend a verification phase of $\dot{V}O_{2max}$ that consists of a maximal or supra-maximal effort 5 - 15 min after a CPx (Costa et al., 2021). Traditionally the CPx is performed on a treadmill and cycle ergometer that is a safe even for high cardiovascular risk patients (Skalski et al., 2012). Furthermore, CPx has limitations in the application, like a need for highly qualified professionals and expensive materials that can reduce large-scale utilization (Skalski et al., 2012).

Indirect alternatives for $\dot{V}O_{2max}$ determination, like the incremental test of Carminatti (TCAR), consist of running back-and-forth, and Shuttle run tests are less expensive than traditional CPx (Léger and Lambert, 1982; Santos et al., 2015). However, the specificity of movement, these tests require a physical space of at least 30 m, a camcorder, and familiarization of up to 4 days (Santos et al., 2015) for the correct execution and reproducibility. Knowing these limitations, proposals of tests and exercises that use alternative methods for incremental testing and greater ecological validity can generate less osteoarticular impact and a lower risk of falls. Also, it can be performed in groups and applied in limited physical space, aiming at the identification of $\dot{V}O_{2max}$ and ventilatory thresholds, which reinforce the specificity of the movement, and are essential for adequate control, prescription, and adherence to physical training.

There is an interest in the prescription of elastic resistance training. This modality is often used to increase strength in different populations (Liao et al., 2017; Mascarin et al., 2017; Mikesky et al., 1994) and can also be used for aerobic training against resistance using an elastic tube. For example, we recently demonstrated that an interval exercise session reduces blood pressure and glucose in older women with and without hypertension (Gasparini-Neto et al., 2021). The sets were composed of running or fast walking (forwards and backward). For this, volunteers used an elastic tube made of latex. The elastic went around the waist and then was attached to the posts of the multi-sport court. Thus, the exercise can be performed in small spaces and with low costs, increasing its applicability during the daily lives of different populations.

However, studies that have validated the CPx using

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elastic resistance is scarce or not available yet, limiting aerobic exercise prescription in this modality. Thus, the objectives of the present study were divided into two analyses: Analysis 1: To propose a new cardiopulmonary exercise test with elastic resistance (CPxEL), comparing the cardiopulmonary and metabolic parameters with those obtained using the conventional running CPx. Analysis 2: To test the reliability and test-retest reproducibility of the CPxEL, enabling the determination of the standard error of measurement (SEM) and the minimal detectable change (MDC) of this procedure. Considering the validity of CPx observed in different ergometers, we hypothesize that CPxEL will present low agreement with CPx and good reproducibility for $\dot{V}O_{2max}$, enabling the determination of specific parameters for the prescription and monitoring of aerobic interval exercise with elastic resistance.

Methods

Participants

The participants were A) eutrophic BMI (≥ 18 and ≤ 25 $kg \cdot m^2$), B) aged between 18 and 35 years, and C) physically active (≥ 150 $min \cdot week^{-1}$ of physical exercise). Participants were excluded when presented with cardiometabolic disease, dietary supplements or anabolic steroids, and suspected respiratory tract infections (e.g., COVID-19). Thus, 26 participants were recruited. Two dropouts for personal reasons occurred during the experiments, and 24 participants completed the experimental design (13 men and 11 women; age 28 ± 4 years; BMI 22.8 ± 2.2 $kg \cdot m^{-2}$; Body mass 66.7 ± 10.2 kg; Height 1.71 ± 0.09 meters. The procedures were approved by the Federal University of Espírito Santo Ethics Committee on Human Research under the CAAE nº 09109319.2.0000.5542 protocol. The participants were required to read and sign an online informed consent containing all information about the procedures and potential risks and benefits involved in study participation. All participants attended and completed the three days of the tests.

Experimental Design

The experiment was a Quasi-Experimental cross-sectional study. The participant attended the laboratory three times in the morning (7:00 am and 10:30 am). Each session was separated by seven days, and the participants were blinded to the session procedures. The body mass and height were collected at the first visit, followed by CPx until voluntary exhaustion. The CPx was performed using a treadmill Super ATL (Inbra Sports, Porto Alegre, RS, Brazil). During the second and third visits, the participants underwent the CPxEL until exhaustion. At the third visit, a verification phase of $\dot{V}O_{2max}$ until voluntary exhaustion was performed after the CPxEL (Figure 1). The participants rested 10-min between the CPxEL and verification phase of $\dot{V}O_{2max}$. Blood samples were collected from the earlobe at baseline and after exhaustion (3, 5, and 7 min of recovery) and dried at -80ºC freezer for posterior analysis. The BORG-CR10 (Arney et al., 2019) rate of perceived exertion scale (RPE) for central effort and the OMNI-RES EB scale adapted for elastic resistance with Thera-Band® (Thera Band®, Akron, OH, USA) (Colado et al., 2014) for peripheric effort were applied at baseline and after each stage. The (heart rate) HR (T31 - CODED - Polar Electro Oy, Kempele, Finland) and the gas exchange ($\dot{V}O_2$ and RER) were continuously recorded.

All procedures were performed at controlled temperature (21 to 24º C). Blood lactate concentrations were determined using an electroenzymatic analyzer, YSI 2300 STAT (Yellow Springs Inc., Yellow Springs, OH, USA). Ventilatory variables were measured breath-by-breath using a Metalyzer 3B metabolic gas analyzer (Cortex Biophysik GmbH, Leipzig, Germany) and analyzed using the Metasoft™ program. Before each test, the Cortex unit was calibrated with a previously known gas sample (16 % O_2 and 5 % CO_2), and the volume was calibrated with a 3-L Hans-Hudolf syringe.

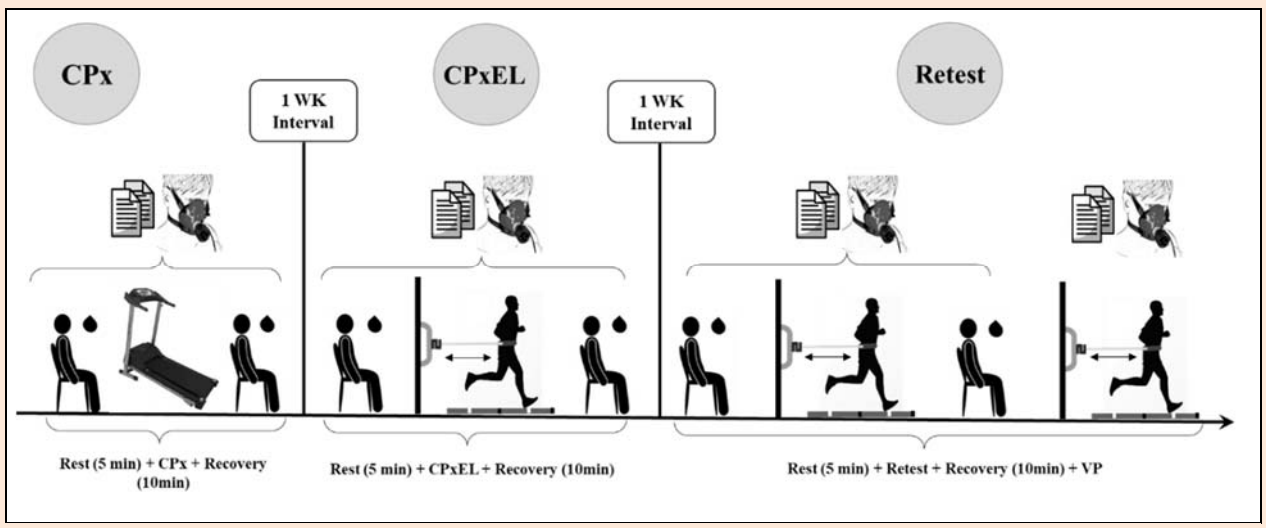

Figure 1. Study design. The procedures were the same for all three incremental tests. Cardiopulmonary Exercise Test (CPx), Cardiopulmonary Exercise Test with Elastic Resistance (CPxEL), and Retest of CPxEL with Verification Phase (VP) of $\dot{V}O_{2max}$ and scales. Legends: Double paper (Perceived Exertion Scales BORG-CR10 and OMNI-RES EB); Participant with mask – ventilatory and gas analysis; Black drop – blood drop for latter blood lactate analysis.

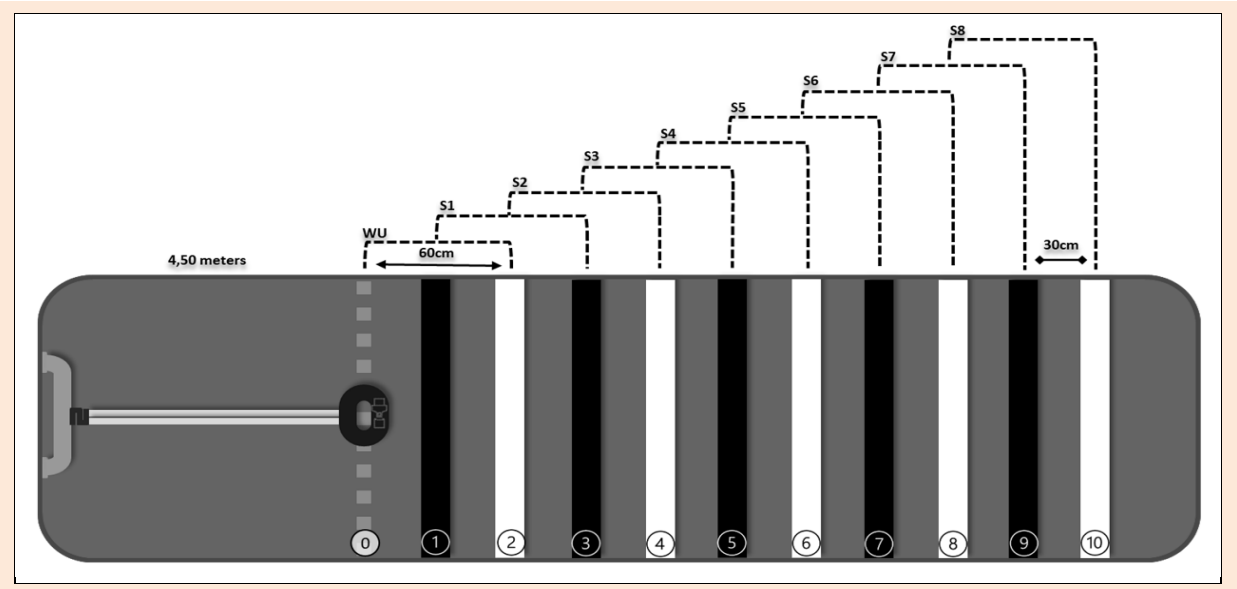

Figure 2. Schematic of the rubberized mat (length of 4.50 meters) demarcated with 11 lines (0-10) – 30 cm between lines. S0 (WU) and 8 (eight) stages (S1 to S8) – 60 cm between stages, interspersed with black and white colors. WU: Warm-up.

Cardiopulmonary Exercise Testing (CPx)

The test was performed on a motorized treadmill maintained at a 1% incline with a 3-minute warm-up walking at 4 km·h^{-1} followed by an incremental running protocol. Increments of 1 km·h^{-1} every min until exhaustion were applied. We aimed protocol durations between 6 and 12 min (Yoon et al., 2007), and verbal encouragement was used at the end of the test. The criteria to identify the test as the maximum was to accept at least three of the following criteria: a) voluntary exhaustion; b) reaching at least 90% of the maximum heart rate predicted by the formula (220 - age); c) respiratory exchange ratio above 1.05 (Slawinski and Billat, 2004); d) $\dot{V}O_{2max}$ identified by the plateau (difference between last stages < 0.05 L·min^{-1}); e) peak lactate ≥ 8.0 mmol·L^{-1} (Goodwin et al., 2007).

Cardiopulmonary Exercise Testing with Elastic Resistance (CPxEL)

CPxEL was carried out on a rubberized mat with 4.5 meters of length demarcated with 11 lines (0 to 10) painted in different colors (white and black) and separated by 30 centimeters. This mat was made from a piece left over from the synthetic flooring for the athletics track (Sportflex SX). We choose 30 centimeters of the distance between the lines (each stage was 60cm) based on previous studies that demonstrated a stride length of 77 cm for eutrophic and 71 cm for obese (Lai et al., 2008) (Figure 2). An adjustable belt with a reinforced closure was initially used, coupled to a 2 m elastic silver tube (®Thera-band Tubing, Malaysia). The elastic band was changed every two weeks or every 2 cm (1%) increase from its original size. In addition, the elastic was tensioned 361 cm in the last stage. There was no tearing and no accident. Finally, the elastic was attached parallel to the ground in a load cell (200 kg; EMG System of Brazil, SP Ltd.). Software for digital acquisition (EMG Lab, version 1.03) collected the force signals at a sampling frequency of 1000 Hz. Data were analyzed using MatLab (MatLab; R2015a®, MathWorks, Massachusetts, USA). The values in millivolts (mV) were converted to kilograms (kg) using a calibration regression constructed through known weights (four measurements between 1 and 9.8 kg). The results represent the mean force at the last 30 s of each stage. Due to signal loss of force data, we analyze 22 and 18 tests for CPxEL and Retest, respectively. Initially, the participant performed a brief familiarization with the protocol. Then, the belt, the silicone face mask for gas collection, and the heart rate sensor T31 coded™ (Polar Electro Oy, Kempele, Finland) were adjusted. The CPxEL consisted of alternating steps back and forth against an elastic resistance attached to a belt. The participant performed steps alternating the feet forward and backward with the back-and-forth movement. The movements were performed using lines with the same color (i.e., first stage using black lines, second stage using white lines, third stage again using black lines, and so on until exhaustion) (Figure 2). At each stage change, the foot that initiated the movement was alternated. After 3 min of warm-up (S0), a protocol consisting of increments of 1 stage (60cm) per minute following a cadence of 200 bpm (beats per minute) in an 8-stage rubber mat was performed. The participants were encouraged to follow a rhythm of 180 bpm (~ 90 steps/min) during warm-up and 200 bpm (~100 steps/min) during the stages emitted by a metronome App (Cifraclub®, Brazil) plugged into a speaker. Pilot testing was performed to determine this cadence with three different cadences (150, 180, and 200 bpm) in 5 participants not included in this study, optimizing the protocol. Constant verbal encouragement was applied to maintain the rhythm during stages. If the participant reached the last stage or, if not possible, increment another stage, 10 (ten) bpm was added every minute until exhaustion (Figure 2).

Ventilatory thresholds determination

Visual criteria and values calculated by the Metasoft™ software were used to determine the ventilatory thresholds. Three evaluators independently and blindly evaluated the results, considering the limits of agreement of at least two of the evaluators (ICC, 0.93). The first ventilatory thresh-

old (VT1) was identified at the time of the lowest point, followed by an exponential increase in the ventilatory equivalent of oxygen ($\dot{V}E/\dot{V}O_2$) without an increase in the ventilatory equivalent of carbon dioxide ($\dot{V}E/\dot{V}CO_2$). V-slope was also used, which indicates the intersection point with the loss of $\dot{V}CO_2/\dot{V}O_2$ linearity and the abrupt increase in $\dot{V}E$ and end-tidal oxygen tension ($P_{ET}O_2$), which usually occurs at approximately 50 to 80% of $\dot{V}O_{2max}$ (Jones and Carter, 2000). In the second ventilatory threshold identification (VT2), the moment of the lowest point of the $\dot{V}E/\dot{V}CO_2$ with subsequent elevation beyond the moment of the gradual decline of the end-tidal carbon dioxide tension ($P_{ET}CO_2$) was considered (Beaver et al., 1986), which usually occurs above 70% of $\dot{V}O_{2max}$ (Jones and Carter, 2000; Poole et al., 2021).

Statistical analyses

Two analyses were performed to respond to the aims of the present study. All statistical analyzes were performed by SPSS software (SPSS Inc., Chicago, IL, USA, Release 16.0.2, 2008) and graphical representation by MedCalc (MedCalc Software Ltd), Acacialaan, Ostend, Belgium, Release 12.5, 2013). Initially, the Shapiro-Wilk test determined data normality, and the homoscedasticity was determined with Bartlett's criteria. Then, descriptive statistical analysis was performed with continuous variables presented as mean and standard deviation (±SD) while categorical variables were expressed as percentage and frequency. All statistical methods were two-tailed, P values were exact, and statistical significance was defined by $P < 0.05$.

First Analysis: To compare the responses observed during the CPx and CPxEL, the paired t-test and Bland-Altman analysis were used. In addition, Pearson's correlation coefficient was assessed. The correlations were classified as trivial (0 - 0.09), small (0.10 - 0.29), moderate (0.30 - 0.49), large (0.50 - 0.69), very large (0.70 - 0.89) and almost perfect (0.90 - 0.99) [16]. The Cohen's *d* from an arbitrary scale was calculated and classified as trivial (0 - 0.19), small (0.20 - 0.49), moderate (0.50 - 0.79), and large (≥ 0.8) (Lakens, 2013; Mukaka, 2012).

Second Analysis: Test-Retest reproducibility of the CPxEL was assessed using paired t-test, typical error (TE), coefficient of variation (CV%), and intraclass correlation coefficient (ICC). The ICC was classified as little or no correlation (0.00 - 0.30); low correlation (0.30 - 0.49); moderate correlation (0.50 - 0.69); high correlation (0.70 – 0.89) and very high correlation (0.90 - 1.00) (Mukaka, 2012). In addition, to assess the sensitivity of the test, the standard error of measurement (SEM) was calculated using the following equation: $SEM = SD \cdot \sqrt{1 - ICC}$, and the minimal detectable change (MDC) was calculated using the following equation: $MDC = [1.96 \cdot \sqrt{2} \cdot SEM]$ (Haley and Fragala-Pinkham, 2006).

Results

First analysis

Table 1 presents the responses observed during CPx and CPxEL. During the CPx, the speed in VT1, VT2, and exhaustion was 7.1 ± 1.1 km·h^{-1}, 11.6 ± 1.73 km·h^{-1}, and 14.2 ± 1.9 km·h^{-1}, respectively. At rest, $\dot{V}O_2$ and Lactate for CPxEL presented higher values than CPx ($P = 0.01$). During the CPxEL, VT1, VT2, and exhaustion stages (S) were WU (S0), S5, and S6, respectively. The delta increases at each stage were 3.3 kg (S1 to S2), 2.2 kg (S2 to S3), 2.0 kg (S3 to S4), 1.5 kg (S4 to S5), 1.6 kg (S5 to S6), 2.4kg (S6 to S7) and 2.9 kg (S7 to S8), respectively. VT1 occurred at 69.7% and 75.3% of HR_{max} and 53.5% and 65.7% of $\dot{V}O_{2max}$.VT2 occurred at 93.3% and 96.8%of the HR_{max} and 87.0% and 96.9% of $\dot{V}O_{2max}$ for CPx and CPxEL, respectively. At VT1, $\dot{V}O_2$ and HR of CPxEL presented higher values than CPx ($P = 0.02$). At VT2, HR, BORG-CR10, and OMNI-RES EB presented higher values for CPxEL ($P < 0.05$). At exhaustion, $\dot{V}O_{2max}$, BORG-CR10, and OMNI-RES EB and test duration presented lower values for CPxEL ($P < 0.05$).

Table 1. Ventilatory and Physiologic parameters were obtained during CPx vs. CPxEL.

		CPx	CPxEL	Bias (LoA)	ES	r
Rest	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	3.7 ± 0.53	**4.0 ± 0.78***	-0.3 (0.9 to -1.54)	0.50 ^{S}	**0.62*** ^{L}
	HR (bpm)	70 ± 13	71 ± 11	-0.9 (14.0 to -15.0)	0.08 ^{N}	**0.81*** ^{VL}
	Lactate (mmol·L)	0.97 ± 0.43	**1.24 ± 0.54***	-0.3 (0.6 to -1.15)	0.54 ^{M}	**0.59*** ^{L}
VT1	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	23.1 ± 6.75	**26.3 ± 4.73***	-3.2 (8.5 to -14.9)	0.55 ^{M}	**0.50*** ^{L}
	HR (bpm)	131 ± 15	**140 ± 15***	-8.9 (19.0 to -36.0)	0.59 ^{M}	**0.57*** ^{L}
	BORG-CR10	2.1 ± 0.8	2.1 ± 1.32	0.0 (2.9 to -2.9)	0.00 ^{N}	0.11 ^{S}
	OMNI-RES EB	2.4 ± 1.13	2.5 ± 1.77	-0.1 (3.4 to -3.6)	0.00 ^{N}	0.31 ^{M}
VT2	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	38.1 ± 6.97	38.8 ± 5.61	-0.7 (7.4 to -8.8)	0.11 ^{N}	**0.81*** ^{VL}
	HR (bpm)	176 ± 12	**180 ± 11***	-3.7 (10.0 to -17.0)	0.34 ^{S}	**0.80*** ^{VL}
	BORG-CR10	4.2 ± 1.2	**5.4 ± 1.61***	-1.3 (1.9 to -4.4)	0.73 ^{M}	0.40 ^{M}
	OMNI-RES EB	5.0 ± 1.38	**5.9 ± 1.75***	-0.9 (3.0 to -4.8)	0.62 ^{M}	0.22 ^{S}
Exhaustion	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	43.8 ± 7.10	**40.0 ± 5.76***	3.8 (12.1 to -4.6)	0.58 ^{M}	**0.80*** ^{VL}
	HR (bpm)	189 ± 10	186 ± 10	3.1 (20.0 to -14.0)	0.30 ^{S}	**0.65*** ^{L}
	Lactate (mmol·L)	10.4 ± 2.5	9.6 ± 2.6	0.8 (5.8 to -4.3)	0.29 ^{S}	**0.48*** ^{M}
	RER	1.07 ± 0.06	1.05 ± 0.04	0.02 (0.13 to -0.09)	0.31 ^{S}	**0.49*** ^{M}
	BORG-CR10	7.5 ± 1.8	**8.5 ± 1.5***	-1.1 (3.1 to -5.3)	0.59 ^{M}	0.18 ^{S}
	OMNI-RES EB	7.6 ± 1.6	**8.6 ± 1.2***	-1.0 (2.4 to -4.4)	0.68 ^{M}	0.29 ^{S}
	Duration (min)	13.2 ± 2.2	**10.1 ± 2.2***	3.2 (6.0 to -0.3)	1.41 ^{L}	**0.78*** ^{L}

VT1: first ventilatory threshold; VT2: second ventilatory threshold; Exhaustion: maximal values; $\dot{V}O_2$: oxygen consumption; HR: heart rate. RER: Respiratory Exchange Ratio; BORG-CR10 and OMNI-RES EB: Perceived Exertion Scales representing central and peripheric effort respectively; Effect Size (ES) and Pearson Correlation (R); N = Null; S = Small; M = Moderate; L= Large; VL = Very large. *CPx versus CPxEL ($P < 0.05$).

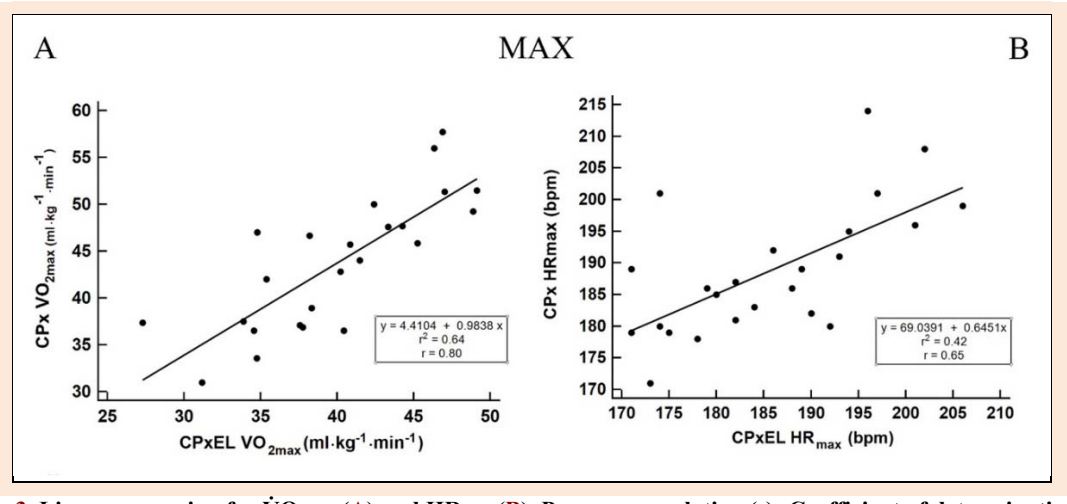

Figure 3. Linear regression for $\dot{V}O_{2max}$ (A) and HR_{max} (B). Pearson correlation (*r*); Coefficient of determination (r^2).

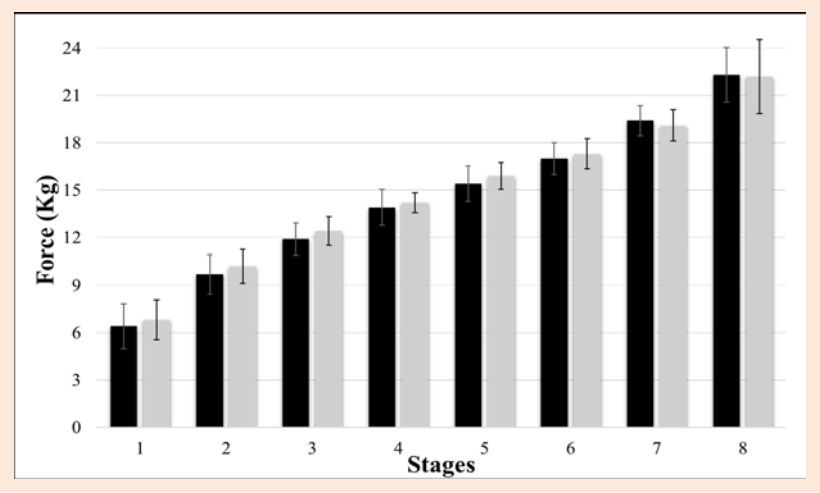

Figure 4. Mean values of force during stages of the test (black bars) and Retest (grey bars) of CPxEL (P ≥ 0.05).

Table 2. Test and retest reproducibility of CPxEL.

		CPxEL	Retest	ES	ET	CV	SEM	MDC	ICC
Rest	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	4.06 ± 0.78	4.25 ± 0.91	0.22 S	0.61	20.7	0.22	0.60	0.652 M
	HR (bpm)	71 ± 11	**75 ± 12***	0.36 S	4.81	9.40	0.57	1.58	0.899 L
	Lactate (mmol·L)	1.24 ± 0.54	1.40 ± 0.46	0.31 S	0.33	35.9	0.10	0.27	0.723 L
VT1	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	26.3 ± 4.73	26.4 ± 4.71	0.03 N	2.67	14.3	0.51	1.41	0.810 L
	HR (bpm)	140 ± 15	138 ± 17	0.10 N	7.63	7.80	1.03	2.85	0.867 L
	BORG-CR10	2.1 ± 1.31	2.4 ± 1.31	0.00 N	1.21	76.5	0.89	2.47	0.271 N
	OMNI-RES EB	2.5 ± 1.76	2.4 ± 1.24	0.00 N	1.32	76.8	0.79	2.20	0.401 S
VT2	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	38.8 ± 5.61	38.1 ± 6.21	0.10 N	2.60	9.50	0.28	0.78	0.893 L
	HR (bpm)	180 ± 11	176 ± 12	0.33 S	6.5	5.20	1.32	3.66	0.812 L
	BORG-CR10	5.5 ± 1.61	5.4 ± 1.71	0.23 S	1.14	29.8	0.35	0.97	0.693 M
	OMNI-RES EB	5.9 ± 1.75	6.0 ± 1.84	0.00 N	1.48	35.2	0.76	2.10	0.488 S
Exhaustion	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	40.0 ± 5.8	41.3 ± 6.0	0.23 S	2.25	7.80	0.19	0.54	0.921 VL
	HR (bpm)	186 ± 10	186 ± 11	0.07 N	3.90	3.00	0.28	0.76	0.930 VL
	Lactate (mmol·L)	9.6 ± 2.57	10.3 ± 3.56	0.20 S	2.36	33.5	1.19	3.30	0.595 M
	RER	1.05 ± 0.04	1.05 ± 0.06	0.05 N	0.04	4.80	0.01	0.03	0.689 M
	BORG-CR10	8.5 ± 1.5	8.8 ± 1.22	0.22 S	1.29	21.0	0.97	2.70	0.247 N
	OMNI-RES EB	8.6 ± 1.0	**9.2 ± 1.0***	0.63 M	0.88	14.0	0.42	1.17	0.570 M
	Duration (min)	10.1 ± 2.22	**10.7 ± 2.53***	0.25 S	0.82	11.1	0.02	0.07	0.937 VL

VT1: first ventilatory threshold; VT2: second ventilatory threshold; Max: maximal values; $\dot{V}O_2$: oxygen consumption; HR: heart rate.; Effect Size: (ES); Typical Error (TE) and Coefficient of Variation (CV%), Standard Error of Measurement (SEM), Minimal Detectable Change (MDC), Intraclass Correlation Coefficient (ICC). N = Null; S = Small; M = Moderate; L= Large; VL = Very large.

Figure 3 represents the linear regression between CPx vs. CPxEL with very large correlation for $\dot{V}O_{2max}$. Confidence interval (CI) was $\dot{V}O_{2max}$ (-8.85 to 17.67 ml·kg^{-1}·min^{-1}; P = 0.49) and HR_{max} (6.75 to 131.3 bpm; P = 0.03).

Second analysis

Figure 4 represents the force observed in each stage of CPxEL (n = 22) and retest of CPxEL (n = 18). No differences were observed between CPxEL and retest

conditions ($P \geq 0.05$) (Figure 4).

Table 2 demonstrates the test-retest reproducibility of CPxEL. VT1 occurred at (65.7% vs. 63.9%) and VT2 at (96.9 vs. 92.3%) of $\dot{V}O_{2max}$. HR in VT1 occurred at (75.3% vs. 74.2%) and VT2 (96.8% vs. 94.5%) for CPxEL and Retest, respectively. VT1 occurred in the WU ($P = 0.731$) and VT2 occurred in S5 ($P = 0.912$) for CPxEL and Retest respectively. The exhaustion occurred at S6 and S7 ($P = 0.271$) for CPxEL and Retest, respectively.

The HR at rest presented higher Retest values than CPxEL ($P = 0.01$). Likewise, OMNI-RES EB and test duration at exhaustion presented higher Retest values than CPxEL.

$\dot{V}O_2$, HR, Lactate, RER, BORG, OMNI-RES EB, and duration presented null or small effect size. Typical error (TE), standard error of measurement (SEM), and minimal detectable change (MDC) presented acceptable and small values, indicating high sensibility and reliability. The coefficient of variation (CV) presented small to large variation for $\dot{V}O_2$, HR, RER, BORG-CR10 at VT1, VT2, and exhaustion. The intraclass correlation coefficient (ICC) was large and very large for VT1, VT2, and exhaustion.

The verification phase (VP) after Retest did not present statistical differences for any variables $\dot{V}O_{2max}$ (41.3 ± 6.0 vs. 39.5 ± 5.88; $P = 0.521$), HR (186 ± 11 vs.182 ± 11; $P = 0.928$), RER (1.05 ± 0.06 vs. 1.0 ± 0.09; $P = 0.328$) and lactate (10.3 ± 3.56 vs. 9.23 ± 2.9; $P = 0.10$), presenting no differences than their incremental value, confirming $\dot{V}O_{2max}$.

Discussion

The present study aimed to propose a new Cardiopulmonary Exercise Test with Elastic Resistance (CPxEL), comparing the physiological responses to conventional cardiopulmonary exercise test (CPx) performed on a treadmill (Analysis 1). In addition, we tested the reproducibility of the CPxEL responses (Analysis 2) in the cardiopulmonary, HR, and metabolic parameters of physically active young people. To the best of our knowledge, this was the first study to investigate whether an incremental exercise test with back-and-forth movements and alternating strides using elastic resistance can be used to measure and reproduce maximal and submaximal capacity (VT1 and VT2). Our main findings highlight the good reproducibility of test and Retest of CPxEL in submaximal and maximal cardiometabolic parameters (VT1, VT2, and Exhaustion).

First analysis

The main findings of our study highlight a good agreement between CPx and CPxEL at VT2 for HR and $\dot{V}O_2$. VT1 showed a high correlation, poor agreement for HR and $\dot{V}O_2$, and a limit of agreement stands out of an expected biological range (Bagger et al., 2003). CPxEL duration had ~ 3min lower than CPx. Although, the average time of the test was 7 min which is considered adequate for an incremental maximal protocol (Yoon et al., 2007). Although some authors indicate the use of 8-12 min of duration to gain a sufficient length of phases to discern the thresholds (Balady et al., 2010; Fletcher et al., 2013), our protocol was sufficient to determine VT1 and VT2 based on the classical criterion. At VT1, the rate of perceived exertion (RPE) did not show differences, which may facilitate exercise prescription at this intensity. BORG-CR10 and OMNI RES EB presented values of 2 and 3 (easy-moderate) in VT1 for CPx vs. CPxEL that does not correspond to the value of 4 (Slightly difficult) found by Seiler and Kjerland (Seiler and Kjerland, 2006). However, it is noteworthy that the participants in the study mentioned above were highly trained athletes who can sustain higher exercise intensities than individuals who are only physically trained (Santos-Concejero et al., 2013), which may have influenced these differences (Millet et al., 2009). Although some differences in the identification of VT1 have been found, which may depend on some factors, such protocols with large or non-linear load increments lead to a delay in O_2 intake response concerning the workload. A delay of 41 seconds or more in O_2 kinetic relating to the workload of ramp slope (> 50 Watts) was found by Davis et al. 1982, and these authors suggested caution in the use of $\dot{V}O_2$ or HR for exercise prescription or performance evaluation at VT1 intensity (Davis et al., 1982). Furthermore, the level of cardiorespiratory fitness (Neves et al., 2021) and the specificity of the movement and muscle recruitment (Millet et al., 2009) can affect the VT1 identification.

On the other side, VT2 showed better agreement and a very large correlation for $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) and HR (bpm), which, despite the statistical difference, did not influence the agreement of these variables. The RPE has numerical differences for presenting different objectives in BORG-CR10, the participants responded to the central effort, and OMNI-RES EB responded to the peripheral effort at the end of each stage. However, despite these differences, they presented the same interpretation value of hard effort (5 and 6). In addition, the RPE found in the present study corresponding to VT2 corroborates the RPE proposed by Seiler and Kjerland (Seiler and Kjerland, 2006), which determines the VT2 between 6 and 7 (hard and very hard), showing that the RPE is an important auxiliary tool to be used to monitor the training load on VT2. It is well known that VT2 is a minimum intensity for high-intensity exercise prescription (Buchheit and Laursen, 2013). On the other hand, the central (BORG-CR10) and peripheral (OMNI-RES EB) RPE was significantly higher for the CPxEL than for the CPx. This difference may be related to the more significant discomfort reported by participants during the test with elastic resistance in which they reported delayed onset muscle soreness in the calf for up to 6 days after CPxEL. The use of elastic resistance modifies the characteristic of muscle contraction. It requires an isometric component more significant than treadmill running, and there is an even greater eccentric contraction that can lead to an increase in mechanisms involved with muscle soreness (Hody et al., 2019). This more intense demand from the muscular system may interfere with the $\dot{V}O_{2max}$ response due to fatigue (Keir et al., 2016), which may explain the moderate effect on the difference of this variable between CPx and CPxEL.

At maximal effort, the $\dot{V}O_{2max}$ and HRmax showed statistical differences between the tests (CPx with higher values than CPxEL). These responses may be related to the

specificity of the ergometer, with the level of physical performance and training specificity (Basset and Boulay, 2000). A previous study with CPx performed on the treadmill showed 10.5% higher $\dot{V}O_{2max}$ than the cycle ergometer (Basset and Boulay, 2000). Despite the statistical differences found in our study, the peak lactate of both tests was similar, and there was a very large correlation between $\dot{V}O_{2max}$ and a large correlation for HRmax. Furthermore, if CPxEL is the only test available, these differences can be corrected by the prediction equation of o $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) ($y = 4.4104 + 0.9838x$) underestimating 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$, allowing exercise prescription by objective variables. Magel et al. (1967) compared a tethered swim test with a CPx on a treadmill, demonstrating slight differences for $\dot{V}O_{2max}$ in CPx (4.20 $L \cdot min^{-1}$) vs. tied swimming (4.14 $L \cdot min^{-1}$) (Magel and Faulkner, 1967). Our results show more pronounceable differences compared with this previous study. Despite this, the tests were carried out in different environments (swimming vs. running), but the use of resistance against the movement performed was similar among the studies. In the study by Pinna et al. (2012), an incremental test with elastic resistance during swimming was proposed, and the HRmax was lower when compared to three other tests with ergometers. Unlike our findings, we did not observe differences in any condition tested for $\dot{V}O_{2max}$ and HRmax (Pinna et al., 2013). In addition, Pessôa-Filho et al. (2017 and 2020), applied a tethered swimming protocol with a rapid gradual increase in the work rate of 0.4 kg applied every 60 seconds until exhaustion and reported that this protocol was fast enough to allow the determination of $\dot{V}O_{2max}$ and ventilatory thresholds precisely (Filho et al., 2020; Pessôa Filho et al., 2017). Our protocol's increase in elastic resistance indicates an s-shape, with a mean of 2.3 ± 0.57 kg of increment after each stage. The minor increment of load (1.5 kg) occurred at stages (S 4-5 and S 5-6). This s-shape increment in our results is according to a previous study that demonstrates the same behavior of silver band elongation until 250% (Uchida et al., 2016). It is important to emphasize that our methodological design between the CPx and CPxEL tests was the same concerning the warm-up time and load increments every 1 minute, which proves to be a test with a low agreement with CPx, but a valid for determining the maximum aerobic capacity according to the specificity of the movement.

Second analysis

We aimed to assess the reproducibility and reliability of the test and Retest of CPxEL. Our findings stand out because we propose an incremental test protocol without the use of ergometers in which we demonstrate good reproducibility of $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$), HRmax (bpm), and force (Kg) in stages (S).

Our findings of high reproducibility reinforce the importance of specificity of movement for the prescription of training using elastic resistance, as previously proposed by our group (Gasparini-Neto et al., 2021). The reproducibility of CPxEL can be confirmed by sensitivity measures such as SEM and MDC, which indicate that the minimum amount of change is not due to measurement variation or error (Haley and Fragala-Pinkham, 2006). $\dot{V}O_2$ and HR showed high to very high reliability and did not differ in the $\dot{V}O_{2max}$ verification phase. Another differential of our study was the confirmation of reproducibility using these sensitivity metrics associated with the low and moderate coefficient of variation, the low typical error, and the small effect size in the CPxEL test and retest differences. The use of these sensitivity methods indicates the good reproducibility of CPxEL (Haley and Fragala-Pinkham, 2006).

Our findings indicate no differences in force production during test and Retest of CPxEL that can be used for training prescription with a single test. Also, our findings' high reproducibility indicates that a single familiarization of the method is enough to conduct this test, while studies that propose to assess the $\dot{V}O_{2max}$ require up to 4 days of familiarization (Santos et al., 2015), doing less practice and accessible.

Limitations and strengths

Some limitations need to be pointed out, our study evaluated only healthy and eutrophic young individuals, and these findings cannot represent the behavior of different levels of physical conditioning, like obese and sedentary individuals. Another limitation was the mixed sample (men and women) because men and women can have until 30% of differences for $\dot{V}O_{2max}$, but another side, a mixed sample increases the ecological validity of results. In addition, the rate of load increment between stages can reduce the reliability of VT1 identification. Future research can apply a smoothed rate of increments after each stage to confirm a better VT1 identification. The main limit is that no workload is obtained unless forces are measured, however, the elastic stretching at each stage has a reference value in a previous study (Uchida et al., 2016). Despite these limitations, it is essential to highlight that our proposal was safe and presented good reproducibility. Thus, we encourage studies that apply our protocol to different populations on a large scale to understand the better application in daily life and the prescription of physical exercise in different intensity domains.

Perspectives

This was the first study to investigate whether an incremental exercise test with back-and-forth movements alternating strides using elastic resistance can be used to measure and reproduce maximal and submaximal capacity.

The present study presents an incremental test with elastic resistance. Consequently, this new approach allows physicians and healthcare professionals to assess physiological indices for an exercise prescription and check cardiorespiratory fitness. Moreover, this new test is possible and interesting to add to traditional tests, not requiring treadmills or ergometers. This test can be performed in the same environments where traditional CPx is applied and can be used as a prescription for interval exercise, allowing central and peripheral adaptations.

Conclusion

The new cardiopulmonary exercise testing using elastic resistance (CPxEL) has good test-retest reproducibility. It represents a possible and interesting add-on to determine

maximal oxygen consumption, heart rate, and second ventilatory threshold without using traditional ergometers but gas exchange measures are still necessary.

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Key points

- The CPxEL represents a possible and interesting add-on to the CPx, not requiring treadmills or ergometers.
- The CPxEL has good test-retest reproducibility and represents a possible and interesting add-on to determine maximal oxygen consumption and heart rate.
- Using back-and-forth movements alternating strides with elastic resistance in an 8-stage rubber mat can be applied to measure maximal ($\dot{V}O_2max$) and submaximal capacity (VT2).

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