# Optimizing a Treadmill Ramp Protocol to Evaluate Aerobic Capacity of Hemiparetic Poststroke Patients

Wendell L. Bernardes,[1] Rafael A. Montenegro,[2,3] Walace D. Monteiro,[1,2] Raul de Almeida Freire,[2] Renato Massaferri,[2,3] and Paulo Farinatti[1,2]

[1]*Graduate Program in Physical Activity Sciences, Salgado de Oliveira University, Rio de Janeiro, Brazil;* [2]*Laboratory of Physical Activity and Health Promotion, Institute of Physical Education and Sports, University of Rio de Janeiro State, Rio de Janeiro, Brazil; and* [3]*Graduate Program in Clinical and Experimental Physiopathology, University of Rio de Janeiro State, Rio de Janeiro, Brazil*

## Abstract

Bernardes, WL, Montenegro, RA, Monteiro, WD, de Almeida Freire, R, Massaferri, R, and Farinatti, P. Optimizing a treadmill ramp protocol to evaluate aerobic capacity of hemiparetic poststroke patients. *J Strength Cond Res* 32(3): 876–884, 2018—A correct assessment of cardiopulmonary capacity is important for aerobic training within motor rehabilitation of poststroke hemiparetic patients (PSHPs). However, specific cardiopulmonary exercise testing (CPET) for these patients are scarce. We proposed adaptations in a protocol originally developed for PSHPs by Ovando et al. (CPET1). We hypothesized that our adapted protocol (CPET2) would improve the original test, by preventing early fatigue and increasing patients' peak performance. Eleven PSHPs (52 ± 14 years, 10 men) performed both protocols. CPET2 integrated changes in final speed (100–120% vs. 140% maximal speed in 10-m walking test), treadmill inclination (final inclination of 5 vs. 10%), and estimated test duration (10 vs. 8 minutes) to smooth the rate of workload increment of CPET1. Peak oxygen uptake ($\dot{V}O_2$peak) (20.3 ± 6.1 vs. 18.6 ± 5.0 ml·kg$^{-1}$·min$^{-1}$; $p = 0.04$), $\dot{V}O_2$ at gas exchange transition ($\dot{V}O_2$-GET) (11.5 ± 2.9 vs. 9.8 ± 2.0 ml·kg$^{-1}$·min$^{-1}$; $p = 0.04$), and time to exhaustion (10 ± 3 vs. 6 ± 2 minutes; $p < 0.001$) were higher in CPET2 than in CPET1. Slopes and intercepts of regressions describing relationships between $\dot{V}O_2$ vs. workload, heart rate vs. workload, and $\dot{V}O_2$ vs. heart rate were similar between CPETs. However, standard errors of estimates obtained for regressions between heart rate vs. workload (3.0 ± 1.3 vs. 3.8 ± 1.0 b·min$^{-1}$; $p = 0.004$) and $\dot{V}O_2$ vs. heart rate (6.0 ± 2.1 vs. 4.8 ± 2.4 ml·kg$^{-1}$·min$^{-1}$; $p = 0.05$) were lower in CPET2 than in CPET1. In conclusion, the present adaptations in Ovando's CPET protocol increased exercise tolerance of PSHPs, eliciting higher $\dot{V}O_2$peak and $\dot{V}O_2$-GET, preventing earlier fatigue, and providing better physiological relationships along submaximal workloads.

**Key Words** cardiopulmonary exercise testing, aerobic exercise, biomechanics, cerebrovascular disease, fitness, health

## Introduction

One of the most common cerebrovascular diseases worldwide is stroke, characterized by partial or total interruption of blood supply to the brain (26). Stroke survivors often exhibit neurological sequels, resulting in functional impairments that include poor mechanical efficiency during daily tasks and reduced cardiopulmonary capacity (30,31). A crucial feature in rehabilitation of poststroke patients is the preservation of motor ability and physical fitness. In addition, lowered physical capacity might increase the risk of stroke recurrence and should be counteracted (18).

For this reason, aerobic training has been recommended as part of neurorehabilitation (3), to improve patients' functional capacity and prevent further events (10,11). The evaluation of aerobic capacity is important to support correct exercise intervention and to evaluate training outcomes. However, walking difficulties associated with motor impairment, particularly hemiparesis are major obstacles to aerobic testing. The assessment of aerobic capacity of poststroke hemiparetic patients should therefore consider some specific characteristics of this group: muscle weakness (21), restricted blood flow and vascular diameter in paretic limbs (2), disturbance in motor unit recruitment and muscle atrophy (15), deficits in motor control and balance (28), and early peripheral fatigue during exercise (19).

In short, specific standardized procedures to assess maximal oxygen uptake ($\dot{V}O_2$max) in poststroke patients are necessary. However, few studies proposed testing protocols for this group (20,22,27). The first cardiopulmonary exercise testing (CPET) designed for stroke patients was

Address correspondence to Dr. Paulo Farinatti, paulo.farinatti@pq.cnpq.br.

32(3)/876–884

*Journal of Strength and Conditioning Research*

proposed by Macko et al. (22). The CPET began with patients walking 2 minutes at comfortable self-selected speed, with treadmill inclination of 0% grade. Subsequently, the speed was increased by 4% and inclination by 2% grade every 2 minutes until volitional fatigue. Later, Mackay-Lyons et al. (20) proposed a test beginning with 2 minutes of walking at self-selected speed and 0% inclination followed by additional 2.5% every 2 minutes until 10% grade. Then, the inclination remained unchanged and speed increased by $0.05\ m\cdot s^{-1}$ every 2 minutes until fatigue. In those protocols, the increase in workload was mainly due to rise in treadmill slope. Despite the caution to ensure that patients walked at constant self-selected speed, there is evidence that inclinations above 5% grade provoke changes in gait biomechanics in both healthy and hemiparetic individuals, with greater joint angles occurring in the hip, knees, and ankles (36,38). Because the hip and knee flexor muscles, as well as ankle dorsiflexors, are often weakened in hemiparetic patients, an excessive treadmill inclination will probably contribute to peripheral fatigue and early interruption of CPETs.

Bearing in mind those limitations, Ovando et al. (27) developed a ramp treadmill protocol, in which comfortable and maximal speeds assessed through 10-m walking tests were used to determine initial (70% comfortable speed) and maximal (40% higher than maximal speed) velocities. This approach increased testing specificity, by considering patients' actual motor capacity. Nonetheless, many of them reported having interrupted the test because of peripheral rather general fatigue, which was suggestive of biomechanical handicap. Factors as excessive final speed or intense treadmill inclination probably concurred to early fatigue in Ovando's protocol. Consequently, it is feasible to think that smoothing its rate of workload increment would attenuate effort perception and prevent peripheral fatigue. Such improvement in exercise tolerance would allow for reaching greater and more realistic $\dot{V}O_2$max values.

Thus, this study investigated whether adaptations in the CPET originally proposed by Ovando et al. (27) (final speed, treadmill inclination, and rate of workload increasing) would improve exercise tolerance of hemiparetic poststroke patients. We compared cardiopulmonary responses, time to exhaustion, and perceived exertion between original and adapted CPETs. It has been hypothesized that changes in Ovando's CPET would allow patients to exercise longer, therefore reaching higher $\dot{V}O_2$ at peak effort and ventilatory thresholds.

## Methods

### Experimental Approach to the Problem

The study was completed within 6 months, including 5 visits to the laboratory. On the first visit, patients answered a medical history questionnaire and underwent clinical examination. On the second visit, patients performed motor function tests (Fulg-Meyer Scale, Berg Scale, and 10-m walking [WK10m] test). On the third day, participants underwent familiarization with treadmill, metabolic cart,

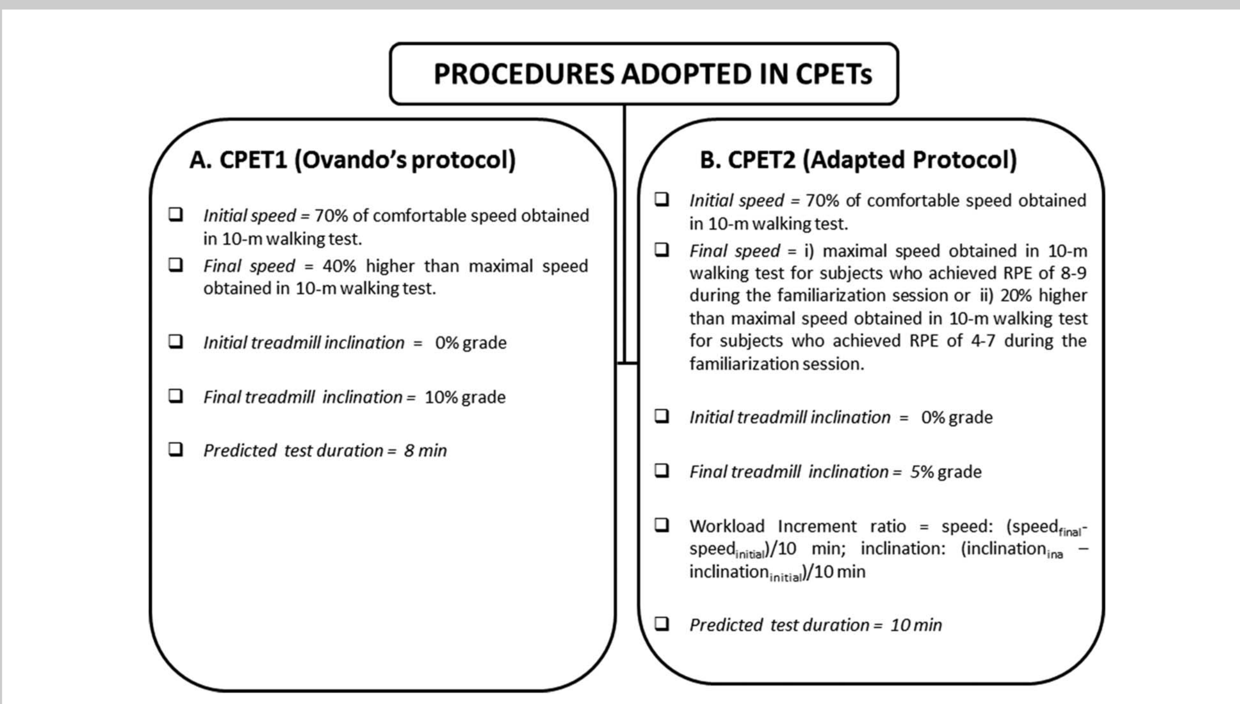


**Figure 1.** Characteristics of CPET1 and CPET2. CPET = cardiopulmonary exercise testing; RPE = rate of perceived exertion.

and perceived exertion scales (Borg CR-10 and perceived walking condition [PWC] scale). On the fourth and fifth visits, CPETs were performed in a randomized counter-balanced order, interspersed with 24–48 hours intervals: (a) The original protocol proposed by Ovando et al. (27) (CPET1) and (b) our adapted protocol (CPET2).

**Subjects**

Poststroke patients should fulfill the following inclusion criteria: (a) right or left hemiparesis for at least 6 months; (b) preserved capacity to walk without supervision; and (c) clearance from a primary physician to perform maximal exercise. Exclusion criteria were as follows: (a) Score in Berg's balance reflecting high risk of falling (scores lower than 36) (24) and (b) Less than 20 points in the lower extremity domain of Fugl-Meyer scale (0–34 points), as reflecting unsatisfactory ambulation capacity without supervision (12).

After advertisement at outpatient clinics of Pedro Ernesto and Gaffrée Guinle University Hospitals, 24 chronic patients volunteered for the study. Thirteen volunteers were excluded because of clinical disorders, as motor or Wernicke aphasia ($n = 2$), uncontrolled cardiac arrhythmia ($n = 2$), carotid stenosis ($n = 1$), uncontrolled hypertension ($n = 3$), advanced gonarthrosis ($n = 1$), biomechanical impairment precluding walking on treadmill ($n = 2$), and voluntary waiver ($n = 2$). Therefore, 11 participants aged 21 to 65 years (10 men; 52 ± 14 years) were eligible and enrolled in the study. The experimental protocol was approved by the Institutional Review Board of the Salgado de Oliveira University (process number 18326013.3.0000.5289), in agreement with the Declaration of Helsinki. All volunteers were informed of benefits and risks of the investigation before signing an institutionally approved informed consent to participate in the study.

**Procedures**

The Fugl-Meyer Scale (12) was applied to evaluate motor impairment in lower limbs, through volitional motion within the abnormal synergic motor function domain. The scores vary from 0 to 34 points (upper limit considered as normal motion). Static and dynamic balance was assessed by means of the Berg scale, in which a maximal of 56 points could be achieved in items ranging from 0 to 4 points (24). Comfortable (self-selected) and maximal walking speeds were determined by WK10m tests (33) performed with 20-minute intervals, to define initial and final speeds applied in CPETs.

*Cardiopulmonary Exercise Testing.* Two CPETs were applied: (a) Ovando's protocol (CPET1) (27); and (b) our adapted protocol (CPET2), which was developed after critical analysis of Ovando's proposal in regards to initial and final speeds, maximum treadmill inclination, workload increment ratio, and predicted test duration. Figure 1 details characteristics of CPET1 and CPET2.

Before performing CPET1 and CPET2, participants underwent familiarization with treadmill, metabolic cart, CR-10 Borg, and PWC scales to minimize fear and increase exercise safety. Familiarization sessions included 2 bouts of walking with 0% incline, separated by 5-minute intervals, at comfortable (5 minutes) and maximal (2 minutes) speeds obtained in WK10m tests. The CPETs were applied in a randomized counterbalanced order, interspersed with intervals of 48–120 hours. Before tests, patients remained seated for 10 minutes in a quiet environment, whereas $\dot{V}O_2$, heart rate (HR), and ventilation

**Table 1.** Demographic, clinical, and functional characteristics of hemiparetic poststroke patients ($n = 11$).

| | Mean ± *SD* |
|---|---|
| Variables | |
| Age (y) | 52 ± 14 |
| Time after stroke (mo) | 24 ± 10 |
| Body mass (kg) | 77 ± 11 |
| Height (cm) | 170 ± 10 |
| Body mass index ($kg\cdot m^{-2}$) | 27 ± 3 |
| Functional scores | |
| Berg's balance scale | 47 ± 4 |
| Motor recovery (0–34–Fugl-Meyer's functional scale) | 28 ± 5 |
| Comfortable speed (10-m walking test, $m\cdot s^{-1}$) | 1.1 ± 0.2 |
| Maximal speed (10-m walking test, $m\cdot s^{-1}$) | 1.4 ± 0.3 |
| | Frequency (%) |
| Comorbity | |
| Coronary arterial hypertension | 7 (63) |
| Diabetes mellitus | 1 (9) |
| Dyslipidemia | 5 (45) |
| Coronary artery disease (revascularization) | 1 (9) |
| Patent foramen ovale | 2 (18) |
| Medications | |
| Beta-blocker | 3 (27) |
| Calcium channel blocker, angiotensin-converting enzyme inhibitor | 5 (45) |
| Acetyl salicylic acid | 5 (45) |
| Sinvastatine | 5 (45) |
| Glifage XR | 1 (9) |

**TABLE 2.** Individual results obtained during CPET1 and CPET2 ($n = 11$).*

| | | WK10m test | | | | Treadmill CPETs | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Subject | Comfortable speed ($km \cdot h^{-1}$) | Maximal speed ($km \cdot h^{-1}$) | Initial/final speed ($km \cdot h^{-1}$) | Initial/final inclination (%) | Rate of increment speed/inclination | Predicted duration (min) | Time to exhaustion (min) | Reason for termination |
| CPET1 | 1 | 3.5 | 4 | 2.4/5.6 | 0/10 | 0.45/1.5 | 8 | 9.0 | Overall fatigue |
| | 2 | 5.2 | 5.8 | 3.6/8 | 0/10 | 0.6/1.5 | 8 | 7.2 | Overall fatigue |
| | 3 | 3.6 | 4.5 | 2.5/6.3 | 0/10 | 0.5/1.5 | 8 | 6.4 | Peripheral fatigue |
| | 4 | 2.2 | 3.5 | 1.5/4.9 | 0/10 | 0.4/1.5 | 8 | 6.0 | Peripheral fatigue |
| | 5 | 3.6 | 5 | 2.5/7 | 0/10 | 0.6/1.5 | 8 | 5.4 | Peripheral fatigue |
| | 6 | 4.7 | 6.5 | 3.2/9 | 0/10 | 0.8/1.5 | 8 | 3.0 | Peripheral fatigue |
| | 7 | 4.8 | 6.4 | 3.3/8.9 | 0/10 | 0.8/1.5 | 8 | 7.0 | Overall fatigue |
| | 8 | 3.6 | 5 | 2.5/7 | 0/10 | 0.6/1.5 | 8 | 6.0 | Peripheral fatigue |
| | 9 | 3.6 | 4.6 | 2.5/6.4 | 0/10 | 0.5/1.5 | 8 | 6.2 | Peripheral fatigue |
| | 10 | 4.6 | 6.5 | 3.2/9 | 0/10 | 0.8/1.5 | 8 | 5.2 | Peripheral fatigue |
| | 11 | 4.2 | 5.5 | 2.9/7.7 | 0/10 | 0.6/1.5 | 8 | 8.0 | Overall fatigue |
| | Mean | 4.0 | 5.1 | 2.7/7.3 | | 0.6/1.5 | | 6.3 | |
| | *SD* | 0.8 | 1.2 | 0.6/1.4 | | 0.1/0.0 | | 1.6 | |
| CPET2 | 1 | 3.5 | 4 | 2.4/5 | 0/5 | 0.3/0.5 | 10 | 9.0 | Overall fatigue |
| | 2 | 5.2 | 5.8 | 3.6/6 | 0/5 | 0.2/0.5 | 10 | 16.0 | Overall fatigue |
| | 3 | 3.6 | 4.5 | 2.5/4.5 | 0/5 | 0.2/0.5 | 10 | 9.2 | Overall fatigue |
| | 4 | 2.2 | 3.5 | 1.5/4.2 | 0/5 | 0.3/0.5 | 10 | 12.0 | Overall fatigue |
| | 5 | 3.6 | 5 | 2.5/6 | 0/5 | 0.4/0.5 | 10 | 11.0 | Overall fatigue |
| | 6 | 4.7 | 6.5 | 3.2/7.5 | 0/5 | 0.4/0.5 | 10 | 5.0 | Peripheral fatigue |
| | 7 | 4.8 | 6.4 | 3.3/6.4 | 0/5 | 0.3/0.5 | 10 | 9.0 | Overall fatigue |
| | 8 | 3.6 | 5 | 2.5/6 | 0/5 | 0.3/0.5 | 10 | 9.0 | Overall fatigue |
| | 9 | 3.6 | 4.6 | 2.5/5.5 | 0/5 | 0.4/0.3 | 10 | 8.0 | Overall fatigue |
| | 10 | 4.6 | 6.5 | 3.2/6.5 | 0/5 | 0.4/0.5 | 10 | 8.0 | Overall fatigue |
| | 11 | 4.2 | 5.5 | 2.9/6.6 | 0/5 | 0.4/0.5 | 10 | 13.0 | Overall fatigue |
| | Mean | 4.0 | 5.1 | 2.7/5.8 | | 0.3/0.5 | | 10.0 | |
| | *SD* | 0.8 | 1.2 | 0.6/1.0 | | 0.1/0.0 | | 2.9 | |

*CPET = cardiopulmonary exercise testing (presently adapted protocol); CPET1 = Ovando's et al. original protocol.

were measured. Pulmonary gas exchanges at rest and during tests were determined using a VO2000 analyzer (Medical Graphics, Saint Louis, MO, USA) and silicone facemask (Hans Rudolph, Kansas, MO, USA). Gas exchange variables were 20-second stationary time averaged, which provided a good compromise between removing noise in data while maintaining the underlying trend (23).

The metabolic cart was calibrated according to manufacturer's instructions before CPETs, using a certified standard mixture of oxygen (17.01%) and carbon dioxide (5.00%) and balanced with nitrogen (AGA, Rio de Janeiro, RJ, Brazil). Flows and volumes determined by the pneumotachograph were calibrated with a syringe graduated for 3-L capacity (Hans Rudolph). Heart rate was measured continuously using an ECG software (Ergo PC Elite 3.3.6.2, Micromed, Brasília, DF, Brazil), and beat-by-beat data were 20-second stationary time averaged. Ambient temperature ranged from 21 to 23° C and relative humidity from 55 to 70%.

Cardiopulmonary exercise tests were considered as maximal when satisfying 3 of 4 criteria (16): (a) score of 10 on Borg CR-10 scale; (b) 90% predicted maximal HR (HRmax = 220 − age) or HR plateau (ΔHR between 2 consecutive work rates $\leq 4$ b·min$^{-1}$); (c) $\dot{V}O_2$ plateau ($\Delta\dot{V}O_2$ between 2 consecutive work rates $<2.1$ ml·kg$^{-1}$·min$^{-1}$); and (d) respiratory exchange ratio (RERmax) $>1.10$. In addition, interruption criteria related to motor control impairment were

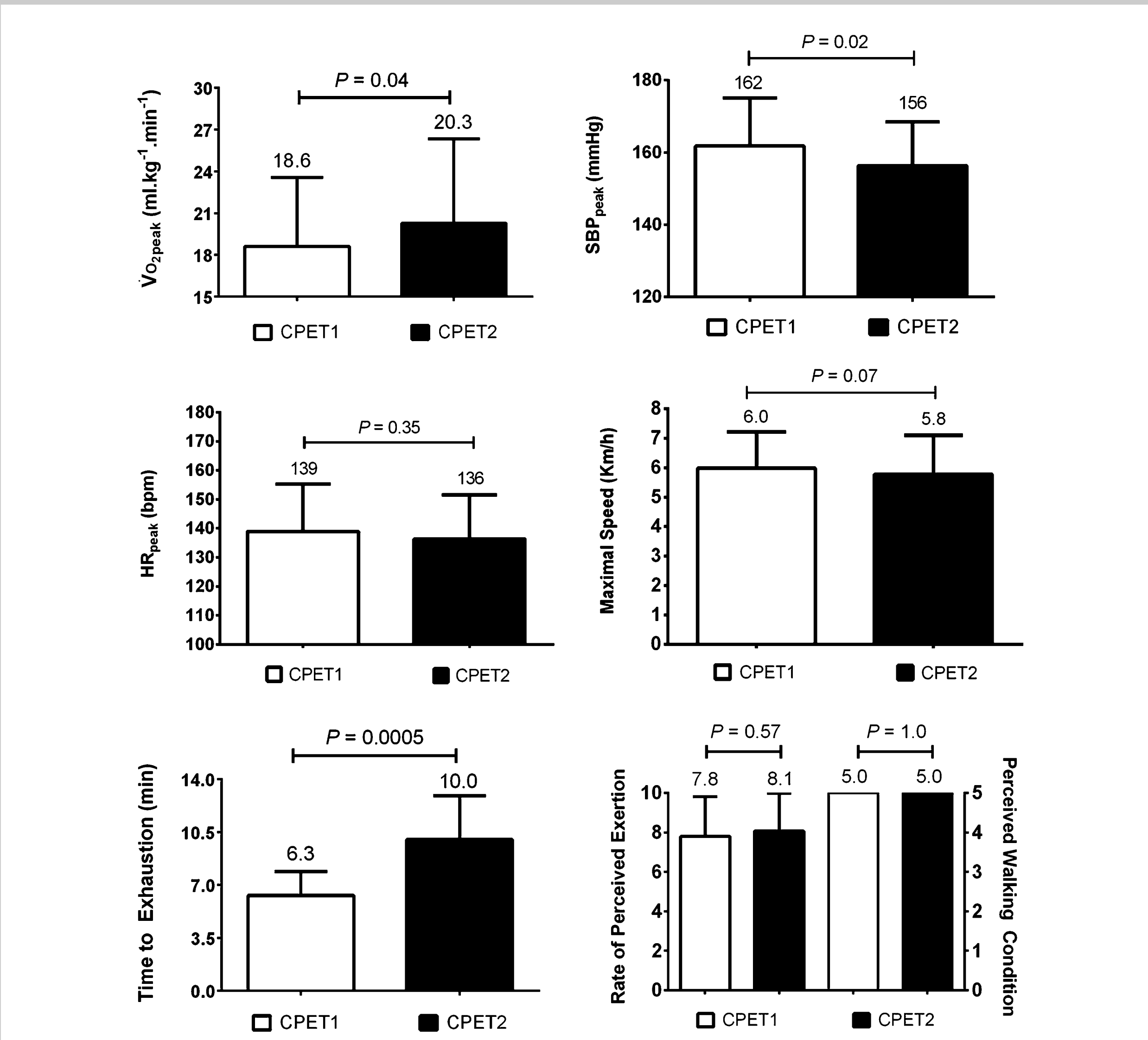


**Figure 2.** Mean (±*SD*) values of peak oxygen uptake ($\dot{V}O_2$peak), systolic blood pressure (SBPpeak), heart rate (HRpeak), maximal speed, time to exhaustion, rate of perceived exertion, and perceived walking condition during Ovando's et al. (CPET1) and the presently adapted (CPET2) protocol ($n = 11$). CPET = cardiopulmonary exercise testing.

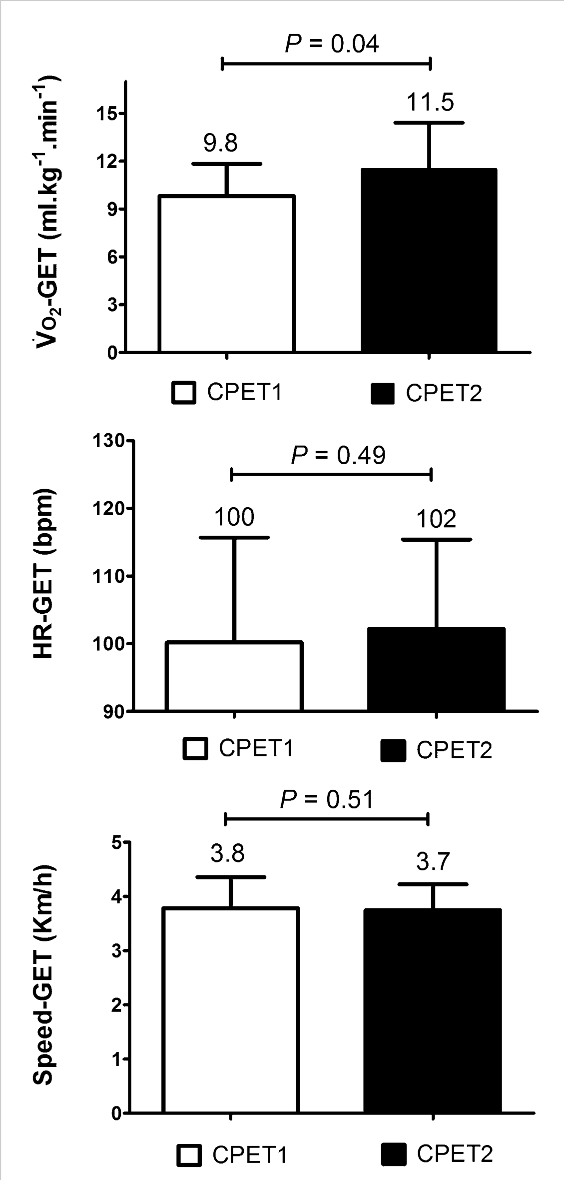


**Figure 3.** Mean (±*SD*) values of oxygen consumption ($\dot{V}O_2$-GET), heart rate (HR-GET), and speed (speed-GET) at the gas exchange transition (GET) during Ovando's et al. (CPET1) and the presently adapted (CPET2) protocol ($n = 11$). CPET = cardiopulmonary exercise testing.

applied: (a) lack of lower limb motor control; (b) presence of lower limb spasticity; (c) gait imbalance; and (d) poor walking efficiency, as reflected by score 5 on PWC scale varying 0–5.

$\dot{V}O_2$ at gas exchange transition (GET) was determined using the combined procedure described by Gaskill et al. (13). Two trained investigators (W.D.M. and R.A.M.) independently determined $\dot{V}O_2$ at GET by visual inspection. If the difference between evaluators was within 3%, the mean value was recorded as result. When the difference exceeded 3%, a third investigator (P.T.V.F.) determined $\dot{V}O_2$ at GET and the average between the 2 closest values was then calculated.

*Rate of Perceived Exertion and Perceived Walking Condition.* Rate of perceived exertion (RPE) was assessed by Borg's CR-10 Scale (6). Perceived walking condition was applied in combination with CR-10 scale, to provide a better assessment of perceived effort in patients showing biomechanical walking impairment (29). Perceived walking condition ranged between 0 and 5 points, according to anchors representing the difficulty to walk on treadmill: "0 = little or no effort; 1 = too easy; 2 = comfortable with moderate effort; 3 = possible to keep going; 4 = still possible to keep going with discomfort; and 5 = very uncomfortable–Stop!" Both CR-10 and PWC scales were positioned in front of patients, and data were collected at the end of each minute of CPETs.

### Statistical Analyses

Data normality was ratified by the Shapiro-Wilk test ,and therefore, results are presented as mean values ± *SD*s. Paired *t*-tests were applied to compare CPET1 and CPET2 in regards to cardiometabolic and physical performance data at peak effort ($\dot{V}O_2$, blood pressure, HR, time to exhaustion, speed, RPE, and PWC) and GET ($\dot{V}O_2$, HR, and speed). In addition, linear regressions per CPET protocol were individually calculated to determine relationships between $\dot{V}O_2$, HR, and workloads ($\dot{V}O_2$ vs. workload, HR vs. workload, and $\dot{V}O_2$ vs. HR). Paired *t*-tests verified potential differences between intercepts and slopes of individual linear regressions across protocols. Paired *t*-tests were also applied to test whether regression models were significantly different from the identity line (intercept and slope of 0 and 1, respectively), as described elsewhere (34,35). Two-tailed statistical significance was fixed at $p \leq 0.05$, and calculations were performed using the softwares Statistica 7.0 (Statsoft, Tulsa, OK, USA) and SAS 6.11 (SAS Institute Inc., Cary, NC, USA).

## Results

Table 1 depicts sample's anthropometric, functional, and clinical characteristics. Patients exhibited mild-to-moderate motor impairment. Nine of them presented comorbidities (i.e., hypertension and dyslipidemia), and 8 took hypertension medication (beta-blockers, calcium channel blockers, or angiotensin-converting enzyme inhibitors).

Table 2 shows individual outcomes obtained in WK10m test (used to determine initial and final speeds in ramp protocols) and in both CPETs. All tests were maximum according to established criteria, and none of participants showed significant ST segment depression or developed chest discomfort. Seven of 11 participants interrupted CPET1 because of peripheral fatigue; whereas in CPET2, this occurred in a single case (subject 6, test duration of 3 vs. 5 minutes in CPET1 and CPET2, respectively).

Figure 2 presents data for $\dot{V}O_2$peak, systolic blood pressure (SBP), HR, maximal speed, time to exhaustion, RPE, and

**TABLE 3.** Mean (±*SD*) values of intercepts, slopes, determination coefficients ($r^2$), and standard errors of estimate (SEE) of regression models calculated for relationships between heart rate vs. workload (HR-W), oxygen uptake vs. workload ($\dot{V}O_2$-W), and heart rate vs. oxygen uptake (HR-$\dot{V}O_2$) during CPET1 and CPET2 ($n = 11$).

| Relationships | Protocols | Y intercept | Slope | $r^2$ | SEE |
|---|---|---|---|---|---|
| HR-W | CPET1 | 14.15 ± 3.8 | 0.96 ± 0.1 | 0.92 ± 0.1 | 3.82 ± 1.0 |
| | CPET2 | 14.78 ± 5.6 | 0.96 ± 0.1 | 0.92 ± 0.1 | 2.95 ± 1.3 |
| | *p* | 0.5 | 0.9 | 0.8 | 0.004 |
| $\dot{V}O_2$-W | CPET1 | 3.21 ± 0.9 | 0.2 ± 0.2 | 0.87 ± 0.2 | 1.41 ± 0.9 |
| | CPET2 | 3.57 ± 1.1 | 0.77 ± 0.1 | 0.77 ± 0.2 | 1.63 ± 1.5 |
| | *p* | 0.3 | 0.3 | 0.7 | 0.5 |
| HR–$\dot{V}O_2$ | CPET1 | 3.74 ± 1.0 | 0.88 ± 0.1 | 0.79 ± 0.1 | 6.0 ± 2.1 |
| | CPET2 | 3.53 ± 1.5 | 0.87 ± 0.2 | 0.78 ± 0.2 | 4.79 ± 2.4 |
| | *p* | 0.5 | 0.6 | 0.8 | 0.05 |

CPET = cardiopulmonary exercise testing; CPET1 = Ovando's et al. original protocol; CPET2 = presently adapted protocol.

PWC, in both CPETs. $\dot{V}O_2$peak was higher in CPET2 than in CPET1 (mean difference: 1.66 ml·kg$^{-1}$·min$^{-1}$; 95% confidence interval [CI], 0.02–3.29; $t = 2.2$; and $p = 0.04$), as well as time to exhaustion (mean difference = 3.6 minutes; 95% CI, 2.00–5.30; $t = 4.9$; and $p < 0.001$). Systolic blood pressure was lower in CPE2 than in CPET1 (mean difference = 5.45 mm Hg; 95% CI, 0.83–10.07; $t = 2.6$; and $p = 0.02$). No difference between CPETs was found for maximal HR (mean difference = 2.5 b·min$^{-1}$; 95% CI, −3.28 to 8.37; $t = 0.9$; and $p = 0.35$), maximal speed (mean difference = 0.21 km·h$^{-1}$; 95% CI, −0.02 to 0.44; $t = 2.0$; and $p = 0.07$), RPE (mean difference = 0.27 units; 95% CI, −1.31 to 0.77; $t = 0.6$; and $p = 0.57$), or PWC (mean difference = 0.0 unit and $p = 1.0$).

Figure 3 exhibits mean values obtained for $\dot{V}O_2$, HR, and speed at GET ($\dot{V}O_2$-GET, HR-GET, and speed-GET). Higher $\dot{V}O_2$-GET (mean difference = 1.7 ml·kg$^{-1}$·min$^{-1}$; 95% CI, 0.06–3.32; $t = 2.3$; and $p = 0.04$) was observed in CPET2 than in CPET1. No significant difference between CPETs was detected for HR-GET (mean difference = 2 b·min$^{-1}$; 95% CI, −8.23 to 4.23; $t = 0.7$; and $p = 0.49$) and speed-GET (mean difference = 0.05 km·h$^{-1}$; 95% CI, −0.09 to 0.17; $t = 0.6$; and $p = 0.56$).

Finally, Table 3 presents intercepts and slopes obtained in individual linear regressions for HR vs. workload (HR-W), $\dot{V}O_2$ vs. workload, and HR vs. $\dot{V}O_2$ (HR-$\dot{V}O_2$) relationships. There was no difference between slopes and intercepts in all regression models. However, CPET2 produced lower standard errors of estimate (SEE) than CPET1 for HR-W (2.95 ± 1.3 vs. 3.82 ± 1.0; $p = 0.004$) and HR-$\dot{V}O_2$ (6.0 ± 2.1 vs. 4.8 ± 2.4; $p = 0.05$) relationships.

## DISCUSSION

The purpose of this study was to propose and evaluate changes to optimize an existing treadmill ramp protocol (27) to assess aerobic capacity of hemiparetic poststroke patients. Adaptations considered biomechanical walking impairments typically found in poststroke patients, to prevent early peripheral fatigue. Maximal and submaximal cardiopulmonary responses as well as RPE and PWC elicited by both protocols were compared. The main findings were as follows: (a) Our protocol (CPET2) induced higher $\dot{V}O_2$peak, $\dot{V}O_2$-GET, and TE, concomitant to lower peak SBP than Ovando's original test (27) (CPET1); (b) Maximal RPE and PWC were similar between CPETs; and (c) Test interruption due to peripheral fatigue was more likely to occur in CPET1 than in CPET2.

The $\dot{V}O_2$max obtained from CPETs is a gold-standard measure of cardiopulmonary capacity (1,14). This marker is used in diagnosis and prognosis of cardiovascular disease (1,14), as well as a parameter, to determine exercise intensity within training programs (37). Previous studies have shown significant $\dot{V}O_2$max attenuation in hemiparetic poststroke patients (5,20) because of hemodynamic and metabolic changes affecting muscle function (4). These changes increase the predisposition to peripheral fatigue (7), depending on hemiparesis severity.

The rate of workload increment in ramp protocols relies on initial/final speeds and grade of treadmill inclination, which is a particularly delicate issue in poststroke patients (20,22). Greater vs. smoother workload increment rates are more likely to provoke early test interruption because of peripheral fatigue. Accumulated evidence indicates that testing duration to assess $\dot{V}O_2$peak and $\dot{V}O_2$-GET should ideally range within 8–12 minutes (25). Our adapted protocol was designed to achieve the final speed by the 10th minute of testing vs. eighth minute in Ovando's protocol (27). This difference probably attenuated workload increment favoring exercise tolerance, which helps to explain the longer TE, as well as greater $\dot{V}O_2$peak and $\dot{V}O_2$-GET observed in CPET2 than in CPET1.

In brief, the lower rate of increment in CPET2 counteracted the propensity to early fatigue during incremental exercise usually observed in poststroke patients, being enough to increase by ~50% the duration of CPET2 in comparison with CPET1. This fact helps to explain why ~64 vs. 9% of patients interrupted the test because of peripheral fatigue in CPET1 and CPET2, respectively. Early test termination was prevented in CPET2 by taking into account typical biomechanical and motor impairments, ratifying our hypothesis that the increase in speed and inclination in CPET1 should be tempered. Consequently, $\dot{V}O_2$peak increased by approximately 20% in CPET2 vs. CPET1 (20.6 ± 6.0 vs. 18.3 ± 5.0 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively).

Our protocol proved to be more adequate for assessing aerobic capacity of hemiparetic patients than previous CPETs developed for these patients. For instance, the mean duration of CPET2 was of 10 ± 3 minutes vs. 9 ± 3 minutes, 8.7 ± 4 minutes, and 6 ± 2 minutes in protocols proposed by Macko et al. (22), Mackay-Lyons et al. (20), and Ovando et al. (27), respectively. The rate of workload increment was of 0.3 ± 0.1 $km \cdot h^{-1}$ and 0.5% incline in CPET2 vs. 0.6 ± 0.1 $km \cdot h^{-1}$ and 1.5% incline in CPET1. The increase of workload in protocols proposed by Macko et al. (22) and Mackay-Lyons et al. (20) was solely based on an abrupt variation in treadmill inclination (from 2.0 to 2.5% grade every 2 minutes). This is evidently problematic in patients typically exhibiting muscle weakness (9). Changes in gait pattern and reduced muscle strength might contribute to early fatigue ensuing that interruption of exercise before actual maximal aerobic capacity is achieved (5,17,32).

In regards to physiological relationships along submaximal workloads, $\dot{V}O_2$-GET corresponded to 57% of $\dot{V}O_2$peak (11.5 $ml \cdot kg^{-1} \cdot min^{-1}$) in CPET2 vs. 47% of $\dot{V}O_2$peak (9.8 $ml \cdot kg^{-1} \cdot min^{-1}$) in CPET1. In their original study with 8 chronic hemiparetic patients, Ovando et al. (27) found a $\dot{V}O_2$-GET of ~73 ± 5% of $\dot{V}O_2$peak. This value is much higher than our data and seems unrealistic for motor handicapped and sedentary patients. Unfortunately, no information concerning the determination of ventilatory threshold was provided by Macko et al. (21) and Mackay-Lyons et al. (20).

Slopes and intercepts of individual regression curves for all relationships between $\dot{V}O_2$, HR, and workload were similar across CPETs. However, SEE was lower in CPET2 than in CPET1 for HR-W and HR-$\dot{V}O_2$ relationships. Overall, these data suggest that CPET2 elicited better physiological transition during incremental exercise than CPET1 (8). In practical terms, these differences might affect the accuracy of workloads or HR corresponding to a given $\dot{V}O_2$, as often applied to determine exercise intensity in aerobic training.

The main limitations of this study were the small sample and lack of stratification concerning hemiparesis severity. Our patients were relatively homogeneous, with mild-to-moderate hemiparesis. Additional cross-validation research with larger samples and different levels of motor impairment is warranted to ratify the external validity of our adapted protocol. Moreover, peripheral fatigue was not quantified by means of objective markers, as blood lactate or electromyography. These data would be useful to ratify the premise that our adaptations to Ovando's original protocol have indeed prevented early local muscle fatigue.

In conclusion, the present changes in initial/final speeds and treadmill inclination optimized Ovando's CPET to assess aerobic capacity of hemiparetic poststroke patients. Our adapted protocol attenuated the rate of workload increment proposed by the original test, eliciting greater walking tolerance and therefore higher $\dot{V}O_2$peak and $\dot{V}O_2$-GET. Furthermore, relationships between $\dot{V}O_2$, HR, and workload during submaximal intensities were improved.

## Practical Applications

This study has evident application for practitioners involved with physical rehabilitation of hemiparetic poststroke patients. The following changes were made in Ovando's original protocol: (a) final speed corresponding to 100–120% instead of 140% of maximal speed attained in WK10m test; (b) final treadmill inclination of 5% instead of 10%; and (c) estimated CPET duration of 10 minutes instead of 8 minutes. These adaptations were capable to smooth the rate of workload increment, preventing early fatigue and increasing performance reflected by higher values of $\dot{V}O_2$peak and $\dot{V}O_2$-GET. The present data might be useful for a better assessment of aerobic capacity in this specific group of patients, therefore optimizing the prescription of aerobic training in rehabilitation programs.

## Acknowledgments

This study was supported by grants from the Brazilian Council for the Technological and Scientific Development (CNPq) and Carlos Chagas Filho Foundation for Research Support in the State of Rio de Janeiro (FAPERJ).

## References

1. Ashley, EA, Myers, J, and Froelicher, V. Exercise testing in clinical medicine. *Lancet* 356: 1592–1597, 2000.
2. Billinger, S. Cardiovascular regulation after stroke: Evidence of impairment, trainability, and implications for rehabilitation. *Cardiopulm Phys Ther J* 21: 22–24, 2010.
3. Billinger, SA, Arena, R, Bernhardt, J, Eng, JJ, Franklin, BA, Johnson, CM, MacKay-Lyons, M, Macko, RF, Mead, GE, Roth, EJ, Shaughnessy, M, and Tang, A. Physical activity and exercise recommendations for stroke survivors: A statement for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke* 45: 2532–2553, 2014.
4. Billinger, SA, Coughenour, E, Mackay-Lyons, MJ, and Ivey, FM. Reduced cardiorespiratory fitness after stroke: Biological consequences and exercise-induced adaptations. *Stroke Res Treat* 959120: 2012, 2012.
5. Billinger, SA, Tseng, BY, and Kluding, PM. Modified total-body recumbent stepper exercise test for assessing peak oxygen consumption in people with chronic stroke. *Phys Ther* 88: 1188–1195, 2008.
6. Borg, GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 14: 377–381, 1982.
7. Chen, CK, Weng, MC, Chen, TW, and Huang, MH. Oxygen uptake response to cycle ergometry in post-acute stroke patients with different severity of hemiparesis. *Kaohsiung J Med Sci* 29: 617–623, 2013.
8. Cunha, FA, Midgley, AW, Monteiro, WD, and Farinatti, PT. Influence of cardiopulmonary exercise testing protocol and resting VO(2) assessment on %HR(max), %HRR, %VO(2max) and %VO(2) R relationships. *Int J Sports Med* 31: 319–326, 2010.
9. De Deyne, PG, Hafer-Macko, CE, Ivey, FM, Ryan, AS, and Macko, RF. Muscle molecular phenotype after stroke is associated with gait speed. *Muscle Nerve* 30: 209–215, 2004.

10. Dean, CM, Richards, CL, and Malouin, F. Task-related circuit training improves performance of locomotor tasks in chronic stroke: A randomized, controlled pilot trial. *Arch Phys Med Rehabil* 81: 409–417, 2000.

11. Duncan, PW, Zorowitz, R, Bates, B, Choi, JY, Glasberg, JJ, Graham, GD, Katz, RC, Lamberty, K, and Reker, D. Management of adult stroke rehabilitation care: A clinical practice guideline. *Stroke* 36: e100–e143, 2005.

12. Fugl-Meyer, AR. Post-stroke hemiplegia assessment of physical properties. *Scand J Rehabil Med Suppl* 7: 85–93, 1980.

13. Gaskill, SE, Ruby, BC, Walker, AJ, Sanchez, OA, Serfass, RC, and Leon, AS. Validity and reliability of combining three methods to determine ventilatory threshold. *Med Sci Sports Exerc* 33: 1841–1848, 2001.

14. Gordon, NF, Gulanick, M, Costa, F, Fletcher, G, Franklin, BA, Roth, EJ, and Shephard, T. Physical activity and exercise recommendations for stroke survivors: An American Heart Association Scientific Statement from the Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention; the Council on Cardiovascular Nursing; the Council on Nutrition, Physical Activity, and Metabolism; and the Stroke Council. *Stroke* 35: 1230–1240, 2004.

15. Hafer-Macko, CE, Ryan, AS, Ivey, FM, and Macko, RF. Skeletal muscle changes after hemiparetic stroke and potential beneficial effects of exercise intervention strategies. *J Rehabil Res Dev* 45: 261–272, 2008.

16. Howley, ET, Bassett, DR Jr, and Welch, HG. Criteria for maximal oxygen uptake: Review and commentary. *Med Sci Sports Exerc* 27: 1292–1301, 1995.

17. Ivey, FM, Hafer-Macko, CE, Ryan, AS, and Macko, RF. Impaired leg vasodilatory function after stroke: Adaptations with treadmill exercise training. *Stroke* 41: 2913–2917, 2010.

18. Kopunek, SP, Michael, KM, Shaughnessy, M, Resnick, B, Nahm, ES, Whitall, J, Goldberg, A, and Macko, RF. Cardiovascular risk in survivors of stroke. *Am J Prev Med* 32: 408–412, 2007.

19. Lerdal, A, Bakken, LN, Kouwenhoven, SE, Pedersen, G, Kirkevold, M, Finset, A, and Kim, HS. Poststroke fatigue–A review. *J Pain Symptom Manage* 38: 928–949, 2009.

20. MacKay-Lyons, MJ and Howlett, J. Exercise capacity and cardiovascular adaptations to aerobic training early after stroke. *Top Stroke Rehabil* 12: 31–44, 2005.

21. Macko, RF, Ivey, FM, Forrester, LW, Hanley, D, Sorkin, JD, Katzel, LI, Silver, KH, and Goldberg, AP. Treadmill exercise rehabilitation improves ambulatory function and cardiovascular fitness in patients with chronic stroke: A randomized, controlled trial. *Stroke* 36: 2206–2211, 2005.

22. Macko, RF, Katzel, LI, Yataco, A, Tretter, LD, DeSouza, CA, Dengel, DR, Smith, GV, and Silver, KH. Low-velocity graded treadmill stress testing in hemiparetic stroke patients. *Stroke* 28: 988–992, 1997.

23. Midgley, AW, McNaughton, LR, and Carroll, S. Effect of the VO2 time-averaging interval on the reproducibility of VO2max in healthy athletic subjects. *Clin Physiol Funct Imaging* 27: 122–125, 2007.

24. Miyamoto, ST, Lombardi Junior, I, Berg, KO, Ramos, LR, and Natour, J. Brazilian version of the Berg balance scale. *Braz J Med Biol Res* 37: 1411–1421, 2004.

25. Myers, J, Buchanan, N, Walsh, D, Kraemer, M, McAuley, P, Hamilton-Wessler, M, and Froelicher, VF. Comparison of the ramp versus standard exercise protocols. *J Am Coll Cardiol* 17: 1334–1342, 1991.

26. O'Donnell, MJ, Xavier, D, Liu, L, Zhang, H, Chin, SL, Rao-Melacini, P, Rangarajan, S, Islam, S, Pais, P, McQueen, MJ, Mondo, C, Damasceno, A, Lopez-Jaramillo, P, Hankey, GJ, Dans, AL, Yusoff, K, Truelsen, T, Diener, HC, Sacco, RL, Ryglewicz, D, Czlonkowska, A, Weimar, C, Wang, X, and Yusuf, S. Risk factors for ischaemic and intracerebral haemorrhagic stroke in 22 countries (the INTERSTROKE study): A case-control study. *Lancet* 376: 112–123, 2010.

27. Ovando, AC, Michaelsen, SM, Carvalho, T, and Herber, V. Evaluation of cardiopulmonary fitness in individuals with hemiparesis after cerebrovascular accident. *Arq Bras Cardiol* 96: 140–147, 2011.

28. Patterson, SL, Forrester, LW, Rodgers, MM, Ryan, AS, Ivey, FM, Sorkin, JD, and Macko, RF. Determinants of walking function after stroke: Differences by deficit severity. *Arch Phys Med Rehabil* 88: 115–119, 2007.

29. Perry, J, Garrett, M, Gronley, JK, and Mulroy, SJ. Classification of walking handicap in the stroke population. *Stroke* 26: 982–989, 1995.

30. Prado-Medeiros, CL, Silva, MP, Lessi, GC, Alves, MZ, Tannus, A, Lindquist, AR, and Salvini, TF. Muscle atrophy and functional deficits of knee extensors and flexors in people with chronic stroke. *Phys Ther* 92: 429–439, 2012.

31. Rimmer, JH and Wang, E. Aerobic exercise training in stroke survivors. *Top Stroke Rehabil* 12: 17–30, 2005.

32. Ryan, AS, Dobrovolny, CL, Smith, GV, Silver, KH, and Macko, RF. Hemiparetic muscle atrophy and increased intramuscular fat in stroke patients. *Arch Phys Med Rehabil* 83: 1703–1707, 2002.

33. Salbach, NM, Mayo, NE, Higgins, J, Ahmed, S, Finch, LE, and Richards, CL. Responsiveness and predictability of gait speed and other disability measures in acute stroke. *Arch Phys Med Rehabil* 82: 1204–1212, 2001.

34. Swain, DP and Leutholtz, BC. Heart rate reserve is equivalent to % VO2 reserve, not to %VO2max. *Med Sci Sports Exerc* 29: 410–414, 1997.

35. Swain, DP, Leutholtz, BC, King, ME, Haas, LA, and Branch, JD. Relationship between % heart rate reserve and % VO2 reserve in treadmill exercise. *Med Sci Sports Exerc* 30: 318–321, 1998.

36. Swanson, SC and Caldwell, GE. An integrated biomechanical analysis of high speed incline and level treadmill running. *Med Sci Sports Exerc* 32: 1146–1155, 2000.

37. Thompson, PD, Arena, R, Riebe, D, and Pescatello, LS. ACSM's new preparticipation health screening recommendations from ACSM's guidelines for exercise testing and prescription, ninth edition. *Curr Sports Med Rep* 12: 215–217, 2013.

38. Werner, C, Lindquist, AR, Bardeleben, A, and Hesse, S. The influence of treadmill inclination on the gait of ambulatory hemiparetic subjects. *Neurorehabil Neural Repair* 21: 76–80, 2007.