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ORIGINAL RESEARCH

Feasibility of Measuring Ventilatory Threshold in Adults With Stroke-Induced Hemiparesis: Implications for Exercise Prescription

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Abstract

Objectives: To assess the feasibility of measuring ventilatory threshold (VT) in adults with walking impairments due to stroke. Secondary objectives are to assess reliability of VT over trials; assess whether participants could sustain treadmill walking at VT; and compare mean heart rate during sustained treadmill walking to estimated heart rate reserve (HRR).

Design: Cross-sectional, single-group design.

Setting: University research laboratory.

Participants: Volunteer sample of adults (N=8) with impaired walking resulting from chronic stroke.

Interventions: Three submaximal treadmill walking tests on 3 separate days; a 30-minute treadmill walking session on a fourth day.

Main Outcome Measures: Gas exchange variables were measured, and 2 independent observers identified VT. Mean heart rate response to treadmill walking at VT was measured and compared with estimated 40% of HRR.

Results: VT was measured successfully in 88% of all trials. There was no difference in VT among trials (P=.17). After multiple imputations to account for 3 missing data points, the intraclass correlation coefficient was .87 (95% confidence interval, .80−.95). All participants were able to walk for 20 minutes at VT. Mean ± SD heart rate during the session was 66.0%±8.0% of estimated maximal heart rate. There was no significant difference between mean heart rate and estimated HRR values (P=.70).

Conclusions: In adults with impaired walking resulting from stroke, VT can be safely measured during submaximal treadmill walking. Participants were able to sustain walking at VT, and this value may provide an appropriate stimulus for aerobic exercise prescription in this population.

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Stroke continues to be the primary cause of serious, long-term disability in the United States, and 795,000 Americans experience a stroke each year.[1] Six months after an ischemic stroke, 50% of older adults still have hemiparesis.[2] People who sustain a stroke typically have premorbidly low physical fitness,[2,3] and they become even more deconditioned after the stroke, partly because of the associated physical limitations that impede mobility and participation in routine exercise.[4]

Aerobic capacity has a strong, inverse association with all-cause mortality in healthy individuals,[5] and in those with cardiac comorbidities[6] and a history of stroke.[7] Even a minimal increase in aerobic capacity[6,8] reduces mortality risk; therefore, aerobic conditioning is an important component of an exercise program after stroke. Physical therapists are instrumental in the rehabilitation of patients after stroke, but do not always incorporate aerobic training into a comprehensive program. Additionally, standard neurorehabilitation is not sufficiently intense to elicit an aerobic training effect.[9] Researchers have reported statistically significant improvements in aerobic capacity after 6-month, moderate-intensity aerobic training programs for stroke patients,[10,11] but improvements have been relatively small, also suggesting that intensity was inadequate to optimize improvements in aerobic capacity. Tang et al[12] noted that for participants in a community exercise program, aerobic capacity improved most

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among those with the lowest baseline capacity. Of 17 participants designated as nonresponders based on a <10% change in peak oxygen consumption, 8 of them had a negative change in peak oxygen consumption. Multivariate regression analysis determined that baseline aerobic capacity was inversely correlated with posttraining changes in peak capacity. Participants exercised at approximately 50% of measured heart rate reserve (HRR), possibly an insufficient training stimulus for participants with higher aerobic capacity.

Aerobic training intensity in the stroke population is typically based on a percentage of HRR, usually 40% to 60% of HRR.[10,13] Potential sources of error exist in using the HRR method for individuals after a stroke. For patients who have impaired lower extremity strength and motor control after a stroke, physical limitations may preclude achieving a maximal heart rate. As a result, the exercise intensity for a patient with such limitations will be underestimated if HRR is based on the maximal heart rate achieved during a treadmill test. Another issue is that medications that blunt the heart rate response to exercise may be prescribed after a stroke. Some 77% of patients experience a first stroke because of high blood pressure[1]; thus, beta-blockers are an important component of poststroke management.[14] Maximal exercise heart rate response has been shown to be reduced by a mean of 21 beats/min in participants taking beta-blockers compared with those not taking beta-blockers,[15] which would reduce the prescribed absolute exercise intensity if maximal heart rate were determined via graded exercise testing. However, it may not be feasible to measure maximal heart rate because exercise to maximal capacity requires a physician's presence in this population according to the American College of Sports Medicine (ACSM) risk stratification guidelines.[14] The ability to prescribe the optimal training stimulus and maximize aerobic capacity may be greater if training workloads are based on a physiological parameter other than heart rate. This is worth exploring because aerobic training is only one of many interventions needed after a stroke; thus a patient's exercise time must be spent wisely.

Rather than using exercise to exhaustion to establish an exercise prescription, the use of a metabolic threshold measurement, such as ventilatory threshold (VT), may provide an appropriate training stimulus on which to establish an aerobic exercise prescription. VT is a noninvasive reflection of anaerobic threshold, representing the exercise intensity above which ventilation increases disproportionately compared with whole-body oxygen uptake.[16] Exercise above VT cannot be sustained very long because of sharp increases in blood lactate, the onset of metabolic acidosis, and a disproportionate increase in respiration to buffer acidosis.[17] Theoretically, VT occurs at the maximal aerobic exercise intensity that can be sustained indefinitely, around 50% to 60% of maximal aerobic capacity ($\dot{V}O_2max$) in sedentary individuals.[18,19] The advantage to measuring VT is that it is safer than measuring $\dot{V}O_2max$ because the patient is not exercising to exhaustion[17-20] and it does not depend on the heart rate response to exercise. VT has been measured to establish aerobic exercise workloads in healthy individuals,[17,21] as well as in patients with cardiac disease[18-20,22] and diabetes.[16] If it is feasible and reliable to measure VT in people after stroke, it may provide the optimal training stimulus for formulating exercise prescriptions in this population.

Based on our hypothesis that VT provides the optimal basis for aerobic training intensity, the primary aim of this pilot study was to determine the feasibility of measuring VT during a submaximal treadmill test in adults with impaired walking resulting from stroke. Secondary aims included assessing the reliability of VT measured on different days, determining whether participants could sustain treadmill walking at VT workloads, and comparing the mean heart rate during a VT treadmill walking session to estimated HRR values. This information is needed to determine whether an aerobic exercise prescription can be based on VT.

List of abbreviations:

ACSM	**American College of Sports Medicine**
ANOVA	**analysis of variance**
CI	**confidence interval**
HRR	**heart rate reserve**
ICC	**intraclass correlation coefficient**
RPE	**rating of perceived exertion**
SEM	**standard error of the mean**
$\dot{V}CO_2$	**carbon dioxide output**
$\dot{V}E$	**minute ventilation**
$\dot{V}O_2$	**oxygen consumption**
$\dot{V}O_2max$	**maximal oxygen consumption**
VT	**ventilatory threshold**

Methods

From July 2013 to January 2014, adults who had a stroke at least 6 months prior were recruited from a community fitness center, stroke support groups, outpatient rehabilitation settings, and physicians' offices. Potential participants were included if they could provide informed consent, understand the evaluation procedures, and follow instructions. Additional criteria included medical stability, including controlled diabetes, hypertension, cardiovascular or respiratory disease; the ability to walk with no more than contact guard assistance with or without an orthosis and/or assistive device on level surfaces; and a willingness to walk on a treadmill for at least 10 consecutive minutes with no more than handrail support and contact guard. Individuals were excluded if they smoked; had active cancer or any uncontrolled medical condition, such as uncontrolled diabetes, hypertension, respiratory, renal, or cardiovascular disease; or had recent surgery.

Procedures

Participants completed 5 sessions in our university research laboratory on 5 separate days, with at least 1 day between sessions. The purpose of session 1 (familiarization trial) was for participants to sign an informed consent form approved by the university's institutional review board. Descriptive measures were subsequently administered to characterize stroke functional status, overground walking speed, and perception of quality of life. Participants were familiarized with treadmill walking and determined self-selected and fast treadmill walking speeds. During the subsequent 3 sessions, VT was measured via a submaximal treadmill test. The final session was a treadmill walking session at VT. Details of study components are presented in the following sections.

Familiarization trial

Participants were fitted with a Polar heart rate monitor,[a] and baseline heart rate and blood pressure were measured. A researcher showed and read the questions of the Stroke Impact Scale to participants and marked participants' responses. Next, the 10-m walk test was administered at self-selected walking speed, followed by the Fugl-Meyer Motor Assessment. Finally, each participant walked