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Estimation of maximal oxygen consumption and heart rate recovery using the Tecumseh sub-maximal step test and their relationship to cardiovascular risk factors

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Abstract *Background:* Maximum aerobic capacity (VO_2max) is associated with lower cardiovascular and total mortality. Step tests can be used to provide an estimate of (VO_2max) in epidemiological or home-based studies. We compared different methods of estimation of VO_2max and heart rate recovery and evaluated the relationship of these estimates with cardiovascular risk factors.
Methods: Data were analysed from 2286 participants in the Tecumseh Community Health Study (>16 y and <70 y) who performed a step test. VO_2max was estimated from heart rate using three methods and the results compared. The magnitude of heart rate recovery (HRR) and the time constant of recovery based on different time intervals post-exercise were also estimated.
Results: Estimated VO_2max showed good or poor agreement depending on the method used. VO_2max correlated inversely with systolic blood pressure (SBP), body mass index (BMI), total cholesterol, blood glucose following a 100 g oral load (PLG) and Framingham risk score. In a multivariable model age sex, cigarette smoking, SBP, BMI and PLG were significantly inversely associated with VO_2max. Correlations with risk factors were strongest for HRR measured over the first 30 s of recovery. Only the time constant calculated from the 3 min post-exercise period correlated significantly with risk factors.
Conclusions: The Tecumseh step test can be used to provide estimates of VO_2max and heart rate recovery. Estimated VO_2max was inversely associated with higher systolic BP, higher BMI and worse glucose tolerance. Measurements of HRR over the first 30 s and the time constant calculate from the first 3 min of recovery correlate most closely with risk factors.

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Introduction

A higher level of cardiorespiratory fitness, assessed as maximum aerobic capacity (VO_2max), is associated with lower cardiovascular and total mortality.[1] However direct measurement of peak oxygen consumption by incremental exercise is time consuming, requires appropriate expertise, and is not entirely without risk.[2] Step testing combined with measurement of heart rate is a convenient, safe and inexpensive submaximal test from which VO_2max can be estimated with acceptable accuracy[3–6] and precision.[7,8] Step tests are particularly appropriate for epidemiological work or studies in the home since steps are easily transportable and stepping technique requires little practice.[9]

However, previously validated equations are test specific, with uncertain transferability to other step tests. Further, most currently validated tests have limitations which reduce applicability. For example, the height of the step employed by McArdle et al.[8] is 40 cm, while the Canadian Home Fitness Step Test is an incremental test with two 20 cm steps. These can be challenging tests for an older population, resulting in poor compliance, and multiple steps are cumbersome for home visits. The Tecumseh step test offers advantages in that it is a 3 min step test which employs a single step with a comparatively low height (20 cm) to ensure that measurement of aerobic capacity is not limited by local muscle fatigue.[10,11] It has been used successfully in children and adults[10,11]; however, information regarding estimation of VO_2max using this test is limited[12] and the relationship of VO_2max estimated by this test to cardiovascular risk factors has not been described. In addition, the rate and extent of heart rate recovery following exercise has been proposed as an indicator of autonomic function[13] and physical fitness[14] and has also been reported to predict future cardiovascular disease and all-cause mortality.[15]

The aim of this study was to compare available equations estimating VO_2max in the Tecumseh study against a validated equation, to determine heart rate recovery, to evaluate the relationship of these estimates with cardiovascular (CVD) risk factors, and to assess the feasibility of estimation of VO_2max and measures of heart rate recovery based only on 2 post-exercise measurements of heart rate (30 s and 3 min post-exercise).

Methods

Sample

The Tecumseh Community Health Study was a longitudinal study of individuals living in Tecumseh, Michigan which commenced in 1957 when all 8800 residents of the 2400 households in Tecumseh were canvassed. Data used in this study were collected over the years 1959–1969 (Round I: 1959–1960, Round II: 1962–1965, and Round III: 1967–1969) and the study achieved a ~88% response rate.[16] In each of three rounds of data collection interviews and medical examinations were conducted with remaining and new household residents, yielding a total of 11,563 persons who were examined at least once and 4312 who were examined during all three rounds.[17] The current work is based on publically available data for those who undertook step tests in Round II.

Step test

For the purpose of this analysis, data were restricted to individuals >16 y and less than 70 y (n = 2286; Table 1). Exclusion criteria for the step test were: known heart disease or stroke, acute severe respiratory infections, severe arthritis or other orthopaedic disabilities, severe hypertension (>170 systolic and/or >110 diastolic) and pregnancy.[10,11] Approximately 84% of study participants in Round II undertook the step test. The step test was administered in an air-conditioned room (22–24 °C) and consisted of stepping onto an 20 cm (8 inch) bench for 3 min at a rate of 24 steps per min using a metronome. This corresponds to ~5 times the rate of resting energy metabolism (~5METS). Heart rates were measured by ECG while the subject was sitting and standing before exercise, during exercise, and at 0.5 1, 2, 3 and 5 min after exercise while the subject was sitting.

Table 1 Sample demographics and average results.

Variable	*N*	Mean	SD
Age, y	2286	35.7	12.0
Male, *N* (%)	1086	48%	
Height, cm	2268	168.0	9.0
Weight, kg	2349	69.2	13.4
Body mass index, kg/m^2	2205	24.6	3.6
Post-load glucose, mg/dl	2136	132.2	39.6
Systolic blood pressure, mmHg	2189	129.9	15.4
Diastolic blood pressure, mmHg	2101	85.1	10.6
Total cholesterol, mg/dl	2235	214.1	44.4
Cigarette smoker, non/current/ex	944/1080/246	42%/48%/11%	
VO_2max(M)	2286	2.33	0.66
VO_2max(S)	2286	2.79	0.65
VO_2max(AVD)	2237	2.35	0.48
HRR30, bpm	2230	25.3	9.2
HRR1, bpm	1600	36.6	11.2
HRR2, bpm	1609	41.7	11.8
HRR3, bpm	1604	42.7	11.3
HRRh3, bpm	1621	17.8	8.3
tc_{0-3}, s	1564	53.7	1.6
tc_{h3}, s	1621	53.5	2.6

Abbreviations: HRR30, heart rate recovery at 30 s; HRR1, heart rate recovery at 1 min; HRR2, heart rate recovery at 2 min; HRR3, heart rate recovery at 3 min; HRRh3, heart rate recovery between 30 s and 3 min; SD, standard deviation; tc_{0-3}, time constant of heart rate recovery over 0–3 min post exercise; tc_{h3}, time constant of heart rate recovery estimated from heart rate at 30 s and 3 min; VO_2max(M), estimated maximal oxygen consumption using Milligan equation; VO_2max(S), estimated maximal oxygen consumption using Sharkey equation; VO_2max(AVD), estimated maximal oxygen consumption using Astrand/Van Dobeln equations. Missing variables account for the different *N*'s. Post-load glucose values were restricted to those receiving 100 g glucose.