VO2Max and Fitness Level Estimated with Speed and Heart Rate

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Athletes and people looking to improve their health need an objective measure of their fitness levels. The maximal oxygen uptake or VO2Max is a direct measure of cardiorespiratory fitness that can reflect changes in endurance and overall exercise capacity. Existing methods of measuring VO2Max are either cumbersome (metabolic carts), test-specific (standardized tests), or insensitive to change (empirical models). We propose a method to automatically measure VO2Max when the user goes for a run. The method only requires a measurement of heart rate and speed and can be used with any wearable system that can provide both measures.

VO2Max is an objective measure of a person's cardiorespiratory fitness. It is the maximal oxygen volume achieved at exhaustion during incremental physical exercise. With proper training, an individual can increase their VO2Max, thus improving their endurance and physical capacity. VO2Max is crucial for athletes and is gaining interest with amateurs training to improve their fitness. In today's digital world, it is highly desirable to obtain such a measure automatically using connected wearables.

The standard way of obtaining VO2Max is through indirect calorimetry to measure oxygen volume. While this method is the gold standard, it suffers from setup complexity because it requires the user to wear a mask and bulky equipment, even in ambulatory measurement. Empirical models to estimate VO2Max from variables such as anthropometric parameters and heartrate (HR) are available, but they do not capture training-induced changes in VO2Max. Submaximal exercise tests such as the Cooper test provide a validated alternative, but they require specific conditions (e.g., fixed distance) and user interaction to input values into regression equations.

We propose a simple, automatic method to estimate VO2Max during running that only requires knowing the user's resting HR, maximum HR, and a measure of HR and speed during a run. The method is based on the linear dependence between HR and speed in running [1]. This relationship is depicted in Figure 1. The method expands on CSEM's previous work on VO2 estimation [2].

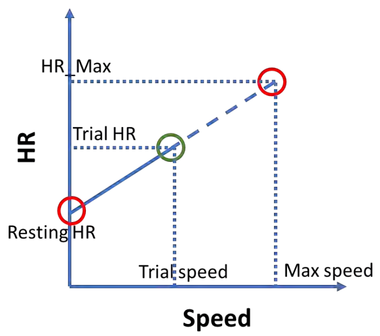

Figure 1. Relationship between speed and HR during running. The green circle represents the speed and HR obtained during a running trial.

The approach was validated on a dataset including 10 subjects (9 men and 1 woman), age range 30–49 years (35.40 ± 6.47 years), weight range 61–87 kg (73.80 ± 7.71 kg), and height range 1.64–1.95 meters (180.00 ± 8.88 cm). The subjects' fitness levels varied from poor to very good.

All subjects were asked to run on a treadmill at incremental preset speeds until exhaustion. Each speed was maintained for three minutes. HR was calculated from an ECG recording, speed was obtained from the treadmill, and VO2Max values were recorded using the Metamax spiroergometer (Cortex, Germany).

The proposed VO2Max estimation method is described as follows: when the user goes for a run, HR and speed values are recorded. Once a period of stable running (i.e., with low HR variability) is detected, the mean HR and speed are calculated (circle representing trial HR and speed on Figure 1) At the end of this step, maximum aerobic speed is calculated by extrapolating the line shown in Figure 1 to the maximum HR. VO2Max is then estimated from the maximum aerobic speed using a known relationship [1].

The results (Figure 2) show that the VO2Max estimation error decreases as the users approach their maximum HR. Based on these results, a minimum ratio of 0.7 can be used to ensure a low-error estimation of VO2Max during a run.

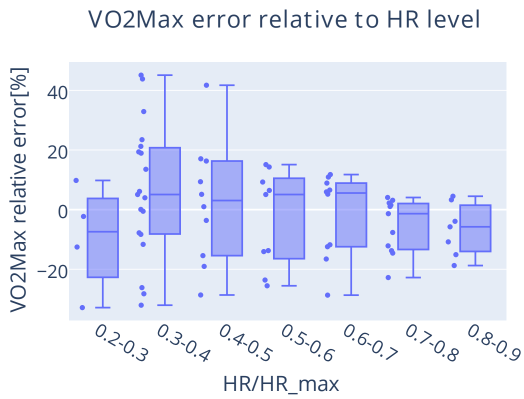

Figure 2. Boxplots of relative VO2Max estimation error as a function of the user's HR/HRmax ratio.

The main limitations of the study are: 1) the protocol was performed indoors on a treadmill, thus not reflecting real-life running, and 2) each speed was held for 3 min, which might be a bit too short to achieve steady-state HR.

The advantages of the proposed method are: 1) it can be used with any device or system measuring speed and HR during running, 2) it is automatic and can be used in real time, embedded systems or in a backend/cloud, 3) it can capture changes in VO2Max induced by training improvements, and 4) the users only need to input their age (or maximum HR, if known).

Subsequent validations with a higher number of subjects and outdoor conditions are foreseen. The algorithm has a low memory cost and computational footprint and is therefore embeddable into any wearable device.

[1] L. Léger, D. Mercier. Gross energy cost of horizontal treadmill and track running. Sports Med. 1984 Jul-Aug;1(4):270-7.

[2] C. Manzoni, A. Carrard, E. Fontana, M. Lemay, M. Bertschi, R. Delgado-Gonzalo.Towards VO2 monitoring: Validation of a heart rate based algorithm. EMBC 2017.