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EVALUATING THE PREDICTIVE PRECISION OF SURROGATE INDICES OF OXYGEN CONSUMPTION

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INTRODUCTION

By definition, one models in the absence of relevant experimental data. Similarly, first-principles prediction equations provide some capacity to predict events or physiological outcomes, when one’s ability to actually take physiological measurements has been compromised. Nevertheless, both tools are limited by the assumptions upon which they are based. Therefore, one must expect that estimations of physiological strain contain some imprecision, and this fact is well accepted.

Many investigators are interested in quantifying the metabolic demands of physically demanding tasks. In some environments, however, it is impossible to measure oxygen consumption as an index of metabolic rate. For instance, an evaluation of the metabolic burden of a search and rescue task within a confined, smoke-filled space with a high water vapour pressure, cannot be undertaken using gas analysis equipment. For such conditions, researchers have turned to surrogate indices of oxygen consumption, with the most commonly used variables being heart rate (Booyens & Hervey, 1960) and minute ventilation (Durnin & Edwards, 1955). As a pilot investigation for a larger project involving lower-, upper- and whole-body exercise, the utility of these two surrogate measures was evaluated in twenty men and women across work rates from rest through to maximal running. In this communication, the precision with which these cardiorespiratory indices, and combinations of indices, predicted oxygen consumption was evaluated.

METHODS

Twenty healthy adults (20-69 years) were recruited into three stature classifications, with equal numbers of males and females in each group: tall (mean height: males = 1.88 m, females = 1.74 m), medium (males = 1.79 m, females = 1.63 m) and short (males = 1.71 m, females = 1.56 m). Dressed in light clothing and running shoes, subjects performed progressive (maximal) running to volitional fatigue. Each test commenced with standing rest (5 min), followed by easy walking (10 min at 4.8 km.h⁻¹, 0% gradient). Treadmill speed was then increased in stages over 5 min, until the desired final running speed was achieved, but the gradient remained unchanged. From the sixth minute, speed was held constant whilst the gradient was increased by 1% every minute until voluntary exhaustion.

Expired gas samples and flows were collected and analysed continuously (TrueOne 2400, ParvoMedics Inc., Utah, USA), with gas analysers calibrated before each block of trials (15.97% O₂, 4.03% CO₂, balance N₂). The following data were derived as 15-s averages: oxygen consumption, carbon dioxide production, breathing frequency, tidal volume and minute ventilation. In addition, heart rate was recorded at 15-s intervals (Advantage, Polar Electro...
Sport Tester, Finland), permitting derivation of the heart rate reserve (maximal minus resting).

From these data sets, values for each of the derived dependent variables were extracted for rest (baseline), and at 5% increments from baseline to peak values (volitional fatigue). These data were then analysed using stepwise, multiple linear regression analyses, wherein five independent predictive indices and four index combinations were used to predict oxygen consumption. For the resulting prediction equations, residuals were determined for each of the corresponding 21 data points extracted for each subject, and averaged to derive a mean prediction error. These parameters were compared using paired t-tests, with alpha set at the 0.05 level.

RESULTS

Due to the advent of portable and reliable heart rate monitors, many seek to predict oxygen consumption from changes in heart rate. However, under the current experimental conditions, the mean prediction error for this index, across all subjects and exercise intensities, was 0.56 L.min⁻¹ (Figure 1). This was significantly better than using breathing frequency (P<0.05), but it was significantly inferior to every other predictive index, or combination of indices with which it was compared (P<0.05).

![Figure 1: Mean prediction errors for each of nine surrogate indices of oxygen consumption. The four leftmost predictions were significantly inferior to each of the other indices (P<0.05). Minute ventilation provided a significantly superior prediction than did the combination of tidal volume and heart rate (P<0.05), but the other differences were not significant (P>0.05). The single index displaying the best predictive power was minute ventilation (mean residual: 0.23 L.min⁻¹), which was significantly better than each of the other single-variable predictions (P<0.05). Adding a second](image-url)
variable to each equation significantly reduced these residuals ($P<0.05$) for all equations except those derived for minute ventilation ($P>0.05$). In fact, for minute ventilation, differences in the mean residuals were only apparent at the fourth decimal place, and therefore provided neither statistically significant nor numerically meaningful difference in the oxygen consumption prediction.

CONCLUSION

These data highlight the need to use heart rate predictions of oxygen consumption with caution, but support the use of minute ventilation (Durnin & Edwards, 1955). Whilst these are neither novel observations (Davies, 1968; Li et al., 1993; Gastinger et al., 2010) nor unexpected outcomes, since oxygen consumption is derived from minute ventilation, we are unaware any comparison of the predictive precision of these cardiorespiratory variables. On the basis of this work, it is concluded that one may halve the prediction error simply by changing from using heart rate to minute ventilation. However, since it is well established that the size of the recruited muscle mass will affect ventilation independently of the external workload (Vokac et al., 1975), then the utility of this index needs to be investigated across different exercise modes, and this is a current research focus of the authors.

REFERENCES


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