Changes in ventilation in response to ramp changes in treadmill exercise load

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Accepted June 30, 1992

Summary. These experiments examined the changes in ventilation during a 40-s ramp increase in exercise load, produced by increasing either the speed of the treadmill or the grade, to equivalent end-points of oxygen uptake. Six subjects underwent five trials each for grade and speed, while ventilation was monitored breath-by-breath. For each subject, ventilation versus time for all five of the speed trials was plotted on a single graph and fitted by linear regression. The data for the grade trials were similarly treated. For all subjects, the slope of the regression line for the speed plots was found to be significantly (P<0.05) greater than that for the grade plots. We concluded that these experimental results support the hypothesis that the neural drive to ventilation persists as exercise continues and is proportionately related to the frequency of limb movement.

Key words: Exercise – Neural drive – Ventilation changes – Treadmill – Speed vs grade

Introduction

The neuro-humoral theory of the respiratory response to exercise, as elaborated by Dejours (1964), recognized both nervous and humoral influences. The abrupt increase in ventilation seen at the onset of moderate exercise (phase 1) was thought to be neurally mediated, and humoral mechanisms accounted for the subsequent rise in ventilation (phase 2) to its steady-state value (phase 3). Since that time, a number of investigators have lent their support to this hypothesis (Maillard and Gautier 1981; Miyamoto et al. 1982; Favier et al. 1983; Dempsey et al. 1985), although other hypotheses have been proposed (see Wasserman et al. 1986 for a review).

Evidence to support an exclusively neural origin for the abrupt increase in phase 1 comes from experiments with widely differing approaches. For example, it has been found that starting exercise after hyperventilation (Lefrancois and Dejours 1964) and in hyperventilated, hypoxic subjects during rebreathing (Duffin and McAvoy 1988), where humoral influences can be presumed to be at a minimum, still produced a rapid initial increase in ventilation. Similarly, phase 1 increases in ventilation were also found to be present in the absence of changes in cardiac output in heart-lung-transplanted patients (Banner et al. 1988), and in pacemaker-controlled patients (Casaburi et al. 1989).

Whether or not the neural stimuli for phase 1 originate from higher motor centres or from limb afferents or from a combination of the two (Krogh and Lindhard 1913; Morikawa et al. 1989), there is evidence that the magnitude of phase 1 is related to the frequency of limb movements rather than to the exercise load in terms of oxygen consumption (Dejours et al. 1959; D’Angelo and Torelli 1971; Assmussen 1973; Duffin and Bechbache 1983; Casey et al. 1987).

The neuro-humoral theory postulates an additive interaction between the neural and humoral components such that the neural component persists throughout exercise until movement ceases (Cunningham 1967; Dejours 1967; D’Angelo and Torelli 1971; Pearce and Milhorn 1977; Morikawa et al. 1989). The evidence for this aspect of the theory is taken from the presence of an abrupt drop in ventilation at the end of exercise when limb movement ceases.

This study was undertaken to examine the postulate that the neural drive persists beyond phase 1 of moderate exercise, and that the magnitude of this drive, during treadmill exercise, is determined by the frequency of limb movements.

Methods

Protocol

Six healthy male subjects between the ages of 20 and 30 years agreed to participate in this study involving treadmill walking of a mild to moderate exercise intensity. All were university students (TS, TR, BA, and PS physiotherapy; MT and JM physiology) and
had received a general course including respiratory physiology as part of their training. All of these students were familiarized with the apparatus and protocol by the experimenter before the testing, but none was aware of the purpose of the experiment, nor, in our judgement, had sufficient expertise to deduce it. All were instructed to abstain from food and caffeinated drink for at least 1 h prior to experiments. Not more than four trials were performed in one session, with at least 15 minutes rest between each trial.

The first part of the experiment was conducted to establish two work loads with the same oxygen uptake for each individual, one walking quickly on a level treadmill, and the other walking slowly on an inclined treadmill. Initially, a maximum walking speed on the treadmill was established by individual preference. Subjects walked as fast as they could comfortably without breaking into a run. After a warm-up period, the subjects walked at this maximum pace while steady-state oxygen consumption measurements were made.

After a suitable rest period, the subjects then walked at a slow pace of 0.89 m s⁻¹ (3.2 km h⁻¹) on a maximally inclined treadmill (25% grade) and had their individual steady-state levels of oxygen consumption re-measured. Each subject then put on a variably weighted vest while walking on the inclined treadmill, and the weight was adjusted so as to achieve the same oxygen consumption as measured while walking on the level treadmill at maximal speed. Once the reproducibility of these equivalent end-points was established, the subjects proceeded to the second stage of the study; the breath-by-breath ventilatory responses to ramp profiles of increasing treadmill speed and grade were monitored.

Subjects performed five speed trials, walking at 0.89 m s⁻¹ on a flat treadmill for 4 min before a smooth progressive increase in speed was made over a 40-s period up to the individually determined maximum speed. The breath-by-breath ventilatory responses over that 40-s period were taken to represent those due to an increase in exercise load brought about by an increase in the frequency of limb movement.

In a second series of five grade trials, subjects again walked at 0.89 m s⁻¹ on a flat treadmill before the treadmill grade was then progressively increased over a comparable 40-s period. These ventilatory responses were taken to represent those due to an increase in exercise load brought about by an increase in limb loading.

Because the obvious differences between the speed and grade trials were perceptible to the subjects, randomization was considered to be irrelevant and the speed and grade trials were presented alternately to each subject so as to minimize effects of long-term trends. Testing was normally completed within a 2-week period. The oxygen consumption levels at the start and end-points of the speed and grade trial exercises were then measured again so as to confirm that they were equal.

**Apparatus**

**Oxygen consumption measurements.** Repeated measures of oxygen consumption were made for each subject walking on the treadmill (Quinton Instruments). Subjects wore a small valve head support (Collins no. 1426) and nose clips while breathing into a three-way valve (Otis-McKerrow) connected to a gas meter (Parkinson-Cowan CD-4). Mixed expired oxygen was sampled by an oxygen analyser (Beckman OM-I). The respiratory parameters were recorded on a chart recorder (Hewlett Packard-Sanborn) and interfaced to a computer (Atari 800XL) where the changes in oxygen consumption were analysed and displayed at each 10-s interval of ventilation. In order to equalize the oxygen uptakes achieved by increasing treadmill speed and grade, subjects wore a multi-pocketed vest that could accommodate 0.5-kg increments of mass.

**Breath-by-breath measurements.** Throughout the second stage of the protocol, subjects wore nose clips and headphones supplying music without a strong rhythmic content in order to isolate them from environmental distractions and minimize the likelihood of the entrainment of their breathing and exercise rhythms to the music rhythm.

The constant-flow, valveless, non-rebreathing circuit used for measuring breath-by-breath ventilation in the second part of the experiment was modelled after the method described by Nunn (1956). Subjects breathed room air through a wide-bore T-piece (37 mm) with a second T-piece connected to a dry-seal, low-inertia spirometer (model 270 Wedge). Rotameters and flow valves were used to match a fixed inflow of air (100 l min⁻¹) to a fixed vacuum outflow. In this configuration, any volume that the subject exchanges with the system is reflected by the spirometer (Bech-bache et al. 1979). Flow, volume and end-tidal carbon dioxide and oxygen were recorded on the chart recorder and computed with the aid of a purpose-built analog-to-digital converter and specially designed software. Calibration of the apparatus was performed daily using a calibrated wet-seal spirometer (Collins) for the volume measurement, and known gas mixtures for the gas analysers.

**Analysis**

In the experimental design, each subject was used as their own control. Graphs of ventilation versus time were created for each of the subjects’ five speed and five grade trials. Combined plots of all five speed trials and all five grade trials were then created, and a regression line was drawn for each individual under both conditions. A variance-ratio test ($P = 0.05$) was conducted to examine the variances within the two cases of speed and grade trials. Subsequently, an analysis of covariance was applied to detect differences between the two slopes of the regression lines (at $P < 0.05$) for each subject. The software used for these analyses was B/STAT by R. W. Wilson for the computer (Atari 800XL).

**Results**

The combined plots of ventilation versus time for each subject are depicted in Fig. 1. Only the critical 40-s period of the ramp increase is represented, without the baseline ventilation. The regression lines are shown on each graph, representing the ventilatory responses to ramp increases in exercise load due to increases in speed and grade.

Table 1 lists the ramp end-point oxygen consumption levels for each subject and the end-point treadmill speeds, and mass added to the vest at 25% grade, used to obtain them. The slopes and coefficients ($r$) of the regression lines shown in Fig. 1 are also listed.

The variance-ratio test was used to examine the variances of the speed and grade slopes, and found that they were significantly different in four of the six subjects ($P < 0.05$) so justifying the use of the analysis of covariance method. This method showed that the difference between the slopes of the speed and grade regression lines was significant ($P < 0.001$) for five of the six subjects. For subject JM the slopes were different, but at a lower level of significance ($P < 0.05$).