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Ventilatory patterns differ between maximal running and cycling

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ABSTRACT

To determine the effect of exercise mode on ventilatory patterns, 22 trained men performed two maximal graded exercise tests; one running on a treadmill and one cycling on an ergometer. Tidal flow-volume (FV) loops were recorded during each minute of exercise with maximal loops measured pre and post exercise. Running resulted in a greater VO_{2peak} than cycling (62.7 ± 7.6 vs. 58.1 ± 7.2 mL kg^{-1} min^{-1}). Although maximal ventilation (V_E) did not differ between modes, ventilatory equivalents for O_2 and CO_2 were significantly larger during maximal cycling. Arterial oxygen saturation (estimated via ear oximeter) was also greater during maximal cycling, as were end-expiratory (EELV; 3.40 ± 0.54 vs. 3.21 ± 0.55 L) and end-inspiratory lung volumes, (EILV; 6.24 ± 0.88 vs. 5.90 ± 0.74 L). Based on these results we conclude that ventilatory patterns differ as a function of exercise mode and these observed differences are likely due to the differences in posture adopted during exercise in these modes.

1. Introduction

The metabolic demands of exercise depend, in part, upon the mode of exercise. For instance, maximal or peak aerobic capacity (VO_{2peak}) is typically 5–11% lower during cycle ergometry than during treadmill running (Astrand and Saltin, 1961; Gavin and Stager, 1999; Hermansen et al., 1970) although trained cyclists have been shown to have a greater VO_{2peak} while cycling compared to running (Stromme et al., 1977). Given the smaller muscle mass recruited while cycling as compared to running, one might expect the ventilatory requirement to be lower as well. Nevertheless, despite a lower VO_{2peak}, ventilation (V_E) at maximal exercise has been shown to be as much as 9% higher while cycling compared to running (Bergh et al., 1976; Gavin and Stager, 1999). This might be due to different regulatory respiratory cues, ventilatory entrainment, different metabolic demands (albeit at similar near maximal or maximal intensities) and/or differences related to the mechanical aspects of ventilation. Biomechanical differences between the two modes of exercise may also play a role, such as rhythm of the legs, torsion of the thorax, movement of the viscera, and movement of the arms. These differences may reflect subtle, but important changes in the integrated balance between the chemical cues and mechanical adjustments made during exercise. Whatever the cause, the observed differences in maximal ventilation with the mode of exercise invite further investigation of how ventilatory 'strategies', i.e., the specific patterns of breathing, might differ between cycle ergometry and treadmill running. The extant literature is incomplete and does not allow sufficient comparisons. In the present report, the 'strategy' or 'patterns of breathing' refer to breathing frequency and lung volumes (tidal volume (V_T), end-expiratory (EELV) and end-inspiratory lung volumes (EILV), etc.) during exercise in these two modalities.

In one of the few papers to compare the cardiopulmonary responses between maximal running and cycling *in the same trained individual*, Gavin and Stager (Gavin and Stager, 1999) observed several key differences. In the 13 subjects tested during two maximal exercise tests, one cycling and one running, maximal cycling resulted in a greater V_E, larger ventilatory equivalents for oxygen (V_E/VO_2) and carbon dioxide (V_E/VCO_2), greater respiratory exchange ratios (RER), and higher arterial oxygen saturations (SpO_2) when compared to running. The greater ventilation achieved during maximal cycling compared to running was a result of greater breathing frequency at the same V_T, prompting the authors to hypothesize that the mechanical limitations to ventilation did not necessarily differ between exercise modes. However, no attempt was made to evaluate or quantify potential mechanical limitations. Based on the relationship between airflow and lung volume, it is possible to suppose that individuals can generate greater expired airflow rates closer to total lung capacity though at a greater metabolic cost. Nevertheless, it is, theoretically possible that differences in breathing strategies (i.e. reflected by differences in EELV and EILV) during maximal cycling as compared to maximal treadmill running allowed subjects to attain a higher minute ventilation during cycling. If this occurs, and perhaps more importantly, *how* this is accomplished, remains to be described.

The flow-volume (FV) loop has been shown to be a valuable tool in the investigation of breathing patterns. First, analysis of the

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FV loop is a method proposed by Hyatt (1961) and more recently employed by Babb and Rodarte (1993) and others (Bartlett et al., 1963; Jensen et al., 1980; Johnson et al., 1995) uses the location of the exercise tidal FV loop within the maximal FV loop to determine an estimation of the ventilatory capacity (V_{Ecap}; i.e. the theoretical maximum ability to ventilate per unit of time). Second, variations in exercise FV loops can be used to describe the mechanics of the pulmonary system based on the lung volume at which ventilation takes place. Differences in FV loops have been noted in elite endurance runners that do, and do not, experience expiratory flow limitation during maximal exercise (Chapman et al., 1998). Studies have also identified differences in FV loops as a result of aging (Johnson et al., 1991b) and differences between patients with pulmonary disease and healthy subjects (Johnson et al., 1995). However, the exercise mode used to challenge the ventilatory apparatus was either cycling (Babb and Rodarte, 1992; Johnson et al., 1995) or running (Chapman et al., 1998; Johnson et al., 1991b), but never both. Previous research, as noted earlier, suggests that different modes of exercise may reflect different ventilatory outcomes. Thus, comparisons of the research using subjects challenged by different exercise modes are, perhaps, not appropriate as the exercise modality itself may be altering the ventilatory outcome independent of the individual performing the exercise.

Therefore, the purpose of this investigation was to determine whether or not the breathing patterns differed between maximal exercise when the same individuals performed both exercise modes. Previous studies have noted differences in V_E between maximal cycling and running and have suggested these differences are due, primarily, to a greater ventilatory drive while cycling (i.e., ventilatory equivalents). The present study is novel because it is the first to compare another regulatory aspect of V_E, the ventilatory strategies undertaken during maximal exercise while cycling and running. We hypothesize that individuals asked to perform maximal exercise in two modes, running and cycling, will exhibit differences in ventilatory strategies. Evidence of the ventilatory constraints and/or advantages imposed by the exercise mode will be made evident by data provided by FV loops and will further explain why V_E during maximal cycling is, generally, greater than that attained during maximal running.

2. Methods

2.1. Subjects

Twenty-two healthy men, who ran, cycled, or indicated both represented their dominant training mode of exercise volunteered for the study. Subjects were initially screened by completing a modified medical questionnaire (PAR-Q) to exclude those with known or suspected pulmonary or cardiovascular disease or disorder. The study was reviewed and approved by the campus Committee for the Protection of Human Subjects. Preceding the first testing session, subjects received a verbal and written explanation of the intent, content, benefits, and risks of the study before providing informed, written consent.

2.2. Experimental sequence and testing protocols

Subjects reported to the laboratory 4 h post-prandial for two separate testing sessions, at least two days apart at roughly the same time of day. Each testing session consisted of a continuous, incremental exercise bout of running on a treadmill (18–60, Quinton, Seattle, WA) or cycling on an ergometer (Monark 886, Varberg, Sweden) to determine maximal aerobic capacity. To reduce the possibility of an order effect, assignment of exercise mode was counterbalanced. During the maximal exercise tests subjects were verbally encouraged to exercise as long as possible. VO_{2peak} was assessed using the following criteria: (1) a heart rate ≥ 90% of the age-predicted maximal heart rate (220 – age), (2) a (RER) ≥ 1.10, and 3) identification of a plateau (≤150 ml) in VO_2 with an increase in workload. If two of the three criteria were met, the highest VO_2 recorded was chosen as the subject's VO_{2peak}. While cycling, 18 out of 22 subjects and, while running, 19 out of 22 subjects met criteria (2 out of 3) to accept the test as a true maximal exercise test, rather than a 'peak.' Because the secondary criteria have been suggested to be problematic (Poole et al., 2008) we refer to both cycling and running as "VO_{2peak}." Height, mass, and lung residual volume (RV) were measured prior to the aerobic capacity test on the first day of testing. A 12-s maximal voluntary ventilation (MVV) maneuver was performed prior to the running aerobic capacity test. During the final 2 min of rest, and during each minute of exercise, the subject performed two maximal inspiratory capacity (IC) maneuvers by filling the lungs to total lung capacity (TLC). The subject was prompted verbally and by a light signal to perform the IC maneuver at the 30-s and 55-s mark of each minute. Once the subjects reached TLC they were instructed to return to their normal, exercise breathing pattern. Previous research has suggested that breathing pattern before or after the IC maneuver is not affected by the performance of the maneuver (Johnson et al., 1999). Prior to and immediately following the exercise bout, each subject performed a series of forced vital capacity maneuvers to obtain maximal flow-volume (MFV) loops in accordance with American Thoracic Society (ATS) standards (Wanger et al., 2005). These maneuvers were performed while standing on the treadmill (prior to treadmill test) and while seated on the cycle ergometer (prior to cycling test). The largest flow volume loop obtained during each exercise mode (either pre- or post-exercise) was selected as the MFV loop.

2.2.1. Treadmill test

Prior to the treadmill test, subjects were provided a warm-up period on the treadmill. This warm up protocol was individualized and selected by the subject. Next, MFV loops were obtained while in the standing position and then subjects rested while seated on a stool for 5 min. During this time all metabolic and ventilatory data was continuously collected (see below). (IC) maneuvers were performed twice every minute to aid in the placement of the tidal flow volume loop within the MFV loop as previously reported (Chapman et al., 1998; Johnson et al., 1992). After 5 min of rest the treadmill speed was gradually increased from a walking speed (~4.8 km h^{-1}) to a comfortable running speed that could be maintained throughout the test (9.6–12.9 km h^{-1}). For the first 2 min of the test, the grade of the treadmill was set to 0%. For the second 2 min, the grade was increased to 4% and then raised by 2% every 2 min thereafter until the subject could no longer continue. Within a 2–3 min following the exercise test a final series of MFV loops were obtained.

2.2.2. Cycle ergometer test

Prior to the cycle ergometer test, subjects were provided a warm-up period on the cycle ergometer. Next, MFV loops were obtained while seated on the cycle ergometer and then subjects rested while seated on the cycle ergometer for 5 min. Subjects' posture on the cycle ergometer was upright with hands placed upon the handlebars, with slight hip flexion and the thoracic cavity slightly leaned forward. During this time, subjects were fitted with a non-rebreathing valve and all metabolic and ventilatory data was continuously collected (see below). IC maneuvers were performed twice every minute to aid in the placement of the tidal flow volume loop within the MFV (Chapman et al., 1998; Johnson et al., 1992). After 5 min of rest a resistance of 1 kp was added to the flywheel of the cycle ergometer. Every 2 min an additional 0.5 kp was added to the flywheel until the subject could no longer continue to exercise. Subjects were required to maintain cycling cadence between 60