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An approach to using heart rate monitoring to estimate the ventilation and load of air pollution exposure☆

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HIGHLIGHTS

- Ventilation estimate has a good correlation with data obtained in the laboratory.
- Statistical models were tested to estimate ventilation based on heart rate.
- Wide variations were found in the regression equations between individuals.
- A statistical model is suitable for situations of heart rate, under 100 beats.

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ABSTRACT

Background: The effects of air pollution on health are associated with the amount of pollutants inhaled which depends on the environmental concentration and the inhaled air volume. It has not been clear whether statistical models of the relationship between heart rate and ventilation obtained using laboratory cardiopulmonary exercise test (CPET) can be applied to an external group to estimate ventilation.
Objectives: To develop and evaluate a model to estimate respiratory ventilation based on heart rate for inhaled load of pollutant assessment in field studies.
Methods: Sixty non-smoking men; 43 public street workers (public street group) and 17 employees of the Forest Institute (park group) performed a maximum cardiopulmonary exercise test (CPET). Regression equation models were constructed with the heart rate and natural logarithmic of minute ventilation data obtained on CPET. Ten individuals were chosen randomly (public street group) and were used for external validation of the models (test group). All subjects also underwent heart rate register, and particulate matter ($PM_{2.5}$) monitoring for a 24-hour period.
Results: For the public street group, the median difference between estimated and observed data was 0.5 (CI 95% −0.2 to 1.4) l/min and for the park group was 0.2 (CI 95% −0.2 to 1.2) l/min. In the test group, estimated values were smaller than the ones observed in the CPET, with a median difference of −2.4 (CI 95% −4.2 to −1.8) l/min. The mixed model estimated values suggest that this model is suitable for situations in which heart rate is around 120–140 bpm.
Conclusion: The mixed effect model is suitable for ventilation estimate, with good accuracy when applied to homogeneous groups, suggesting that, in this case, the model could be used in field studies to estimate ventilation. A small but significant difference in the median of external validation estimates was observed, suggesting that the applicability of the model to external groups needs further evaluation.

Abbreviations: $PM_{2.5}$, particulate matter less than 2.5 μm; logVE, logarithm of ventilation; CI, confidence interval.
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1. Introduction

Short- and long-term exposures to vehicular pollution are associated with increased morbidity and mortality, primarily due to cardiorespiratory diseases (Brunekreef et al., 2009; HEI, 2010; Krewski et al., 2009).

A comparative risk assessment of 21 regions of the world indicated that from 1990–2010, approximately 3.2 million lives (6.1% of all fatalities) were lost and 76 million (3.1%) disability adjusted life years (DALYs) could be attributed to particulate matter ($PM_{2.5}$) pollution (Lim et al., 2012). The main source of pollution in urban centers is vehicular. To estimate the effects of pollution on health, most studies, including both cohort (Pope et al., 2002) and time series (Santos et al., 2008), have used fixed samplers. Almost 20 years ago, a study conducted in England (Watt et al., 1995) compared the use of personal air sampling versus fixed samplers and showed higher values in the individual samplers. This study was followed by others which compared the use of individual samplers (Brunekreef et al., 2009; Jansen et al., 2005; de Hartog et al., 2010). Since then, several studies have been published to obtain a better individual pollutant exposure estimate; these studies have been used, both for general population (Dons et al., 2012) and for specific groups, such as policemen, taxi drivers, couriers, and traffic agents (Lioy et al., 2011; Tomei et al., 2001; van Roosbroeck et al., 2006). Despite the fact that fixed samplers are still widely used because of their lower costs, under certain conditions their estimates do not appear to differ significantly from personal samplers in individuals who were not exposed to environmental tobacco smoke (Brunekreef et al., 2005).

However, most studies do not take into account the performance of different physical activities during the day, which determines the ventilation variation and the inhaled air volume. It is difficult to measure ventilation in field studies. To circumvent this limitation, some studies (Mermier et al., 1993; Samet et al., 1993) have attempted to estimate ventilation using heart rate, which is easily measured by portable heart rate monitors. Although heart rate is influenced by factors such as temperature, time, and stress, heart rate displays a good correlation with oxygen consumption and ventilation (Samet et al., 1993; Zuurbier et al., 2009). This ultimately allows for the estimation of the exposure load per individual and provides an association with biological indicators (blood, lung function, heart rate, etc.).

Studies have found (Mermier et al., 1993; Zuurbier et al., 2009) that the equation obtained using the ventilation and heart rate data of each individual provides a more accurate estimate of individual ventilation, but equations developed based on a group of individuals can also be used to estimate ventilation in population groups. However, these studies (Mermier et al., 1993; Zuurbier et al., 2009) did not test for the model's external validity and some doubts still remain about whether the equations developed from cardiopulmonary exercise test (CPET) in the laboratory can be used to estimate ventilation in other individuals with similar activities using 24-hour heart rate monitoring.

The results found in the study aforementioned (Zuurbier et al., 2009) could not be compared with the results found in Belgium (Int Panis et al., 2011). Direct ventilation measurements were performed in the field and the study showed that ventilation in cyclists was 4.3 times higher than in car passengers (Int Panis et al., 2010), which was two times higher than ventilation measurements found in The Netherlands (Zuurbier et al., 2009). This could be partly explained by the difference in cycling speed, 12 km/h (Zuurbier et al., 2009) and 20 km/h (Int Panis et al., 2011), but also, the method of direct ventilation measurement may have had high influence.

The aim of this study was to develop and evaluate models to estimate ventilation, based on heart rate, which can be used to estimate the inhaled load of pollutants, in field studies.

2. Methods

2.1. Assessed individuals

The participants in this study took part in a larger study, titled “Evaluation of pollution toxicity by particulate matter generated by different emission sources: clinical and experimental studies proposition”, with partially published results (Torricelli et al., 2013). This study included male nonsmokers or those who had quit smoking for at least one year and aged between 18 and 65 years. The non-smoking status was confirmed by exhaled CO measures, determined in ppm by a Micro CO Meter, Micro Medical Limited (Rochester, England).

Individuals with different exposures to air pollution were selected. Employees of the Forest Institute, which is located in a park 13 km distant from central São Paulo City, Brazil, with low pollution exposure, and traffic controllers and taxi drivers, who worked in the broad central section of São Paulo, with high exposure to vehicular pollution, were recruited during workplace meetings or through newspaper advertisements. The individuals who met the inclusion criteria answered a questionnaire on working conditions, demographic data and comorbidity history, followed by clinical examination. Individuals with medical conditions that would not allow the evaluations to be accomplished were excluded.

Within the 65 selected individuals who were evaluated, eight were traffic controllers, 38 were taxi drivers and 19 were park rangers. Five individuals (three taxi drivers and two park rangers) were excluded, because they could not finish CPET: four presented a diastolic blood pressure higher than 120 mm Hg and one subject presented reduction in the systolic blood pressure higher than 20 mm Hg.

The studied individuals were divided in 3 groups: the park group, consisted of park rangers; the public street group, consisted of traffic controllers and taxi drivers; and the test group, consisting of 10 individuals randomly selected from public street group to evaluate the consistency of the models evaluated in the study. In this way, 17, 33 and 10 individuals were evaluated in park, public street and test group, respectively.

All of the participants agreed to participate in the study and signed an informed consent form. The study was approved by the Ethics Committee for Research Projects Analysis of the Hospital das Clínicas, Medical School, University of São Paulo (CAPPesq 0565/07).

2.2. Study protocol

The individuals were selected and evaluated between October 2010 and June 2012. They underwent assessments on two different and consecutive days during the morning. On the first day a technician installed the portable heart rate monitor and the $PM_{2.5}$ individual sampler for recording in the field over a 24-hour period. On the second day the equipment was removed, they answered a questionnaire concerning the occurrence of any cardiopulmonary complications that could interfere with the tests, underwent a spirometry, and performed the CPET.

2.3. Pulmonary function test

Spirometry was performed with a KoKo spirometer (Pulmonary Data Services Instrumentation Inc., Louisville, USA) according to the ATS/ERS recommendations (Miller et al., 2005a, 2005b). We applied the predicted values of normality for a Brazilian population (Pereira et al., 2007) and used the interpretive criteria recommended by the ATS/ERS (Pellegrino et al., 2005).

2.4. Cardiopulmonary exercise test

All of the subjects were assessed in the morning. After a five-minute rest, each volunteer was positioned on an electromagnetic brake cycle ergometer (Encore Vmax 29S model, VIASYS, USA). The test began