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Determinants of maximal oxygen uptake ($VO_{2\ max}$) in fire fighter testing

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ABSTRACT

The aim of this study was to evaluate current daily practice of aerobic capacity testing in Belgian fire fighters. The impact of personal and test-related parameters on the outcome has been evaluated.

Maximal oxygen uptake ($VO_{2\ max}$) results of 605 male fire fighters gathered between 1999 and 2010 were analysed. The maximal cardio respiratory exercise tests were performed at 22 different centres using different types of tests (tread mill or bicycle), different exercise protocols and measuring equipment.

Mean $VO_{2\ max}$ was 43.3 (SD = 9.8) ml/kg.min. Besides waist circumference and age, the type of test, the degree of performance of the test and the test centre were statistically significant determinants of maximal oxygen uptake.

Test-related parameters have to be taken into account when interpreting and comparing maximal oxygen uptake tests of fire fighters. It highlights the need for standardization of aerobic capacity testing in the medical evaluation of fire fighters.

1. Introduction

Fire fighting is a physically demanding profession even though the number of interventions and occupational demand during a 24-hour shift might be low. At an emergency scene, fire fighters perform a series of actions under stressful conditions, such as moving and lifting heavy weights and rescuing victims while wearing protective clothing and a self-contained breathing apparatus (SCBA). The total weight of the equipment and SCBA is around 21–22 kg. As such, it increases the energy demand significantly (Baker et al., 2000; Dreger et al., 2006; Selkirk and Mc Lellan, 2004).

Bos et al. (2004) conducted a field study during eighty-five 24 h shifts in Dutch fire stations and they concluded that two tasks (SCBA and Inside tasks) in actual fire fighting exceed the guideline for energetic workload of Wu and Wang (Wu and Wang, 2001, 2002). This guideline consists of prediction models on the relationship between the percentage of heart rate reserve (%HRR) and the acceptable work duration (MAWD) for both short and long periods of work. The real duration of the "Inside and SCBA" tasks were 23 and 21 min; the corresponding MAWDs are 17 and 4 min respectively. In addition, fire fighters are exposed to high temperatures, which further stresses the cardiovascular system (Barr et al., 2010; Bruce-low et al., 2007; Selkirk and Mc Lellan, 2004).

Heart rates measured during normal fire fighting tasks are at or near maximal levels (Bos et al., 2004). Elsner and Kolkhorst (2008) found the oxygen uptake associated with performing live fire rescue and suppression tasks were around 62% of the VO_{2max}. According to an investigation of Bilzon et al. (2001) metabolic demands of simulated shipboard fire fighting tasks could reach up to peaks of 43 ml oxygen/kg/min, being equivalent to 82% of VO_{2max}. Consequently, it is imperative that fire fighters are physically fit to perform their job and to guarantee their own safety as well as the safety of their colleagues and victims. Numerous studies have demonstrated the necessity of maintaining a high level of aerobic capacity for rescue personnel such as fire fighters (Bilzon et al., 2001; Bos et al., 2004; Elsner and Kolkhorst, 2008).

Leading researchers and agencies recommend that the measurement of aerobic capacity would be included in the medical examination of fire fighters. The measurement of aerobic capacity is recommended to be part of the medical examination of fire fighters by leading researchers and agencies (Ben-Ezra and Verstraete, 1988; Elsner and Kolkhorst, 2008; International Association of Fire Fighters, 2008; Peate et al., 2002). VO_{2max} is used as a measure of aerobic capacity. Investigations of fire fighting activities

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have led to minimal requirements for $VO_{2max,}$ ranging from 33.5 ml/kg/min (Sothmann et al., 1990) to 41 (Bilzon et al., 2001) and 45 (Gledhill and Jamnik, 1992) ml/kg/min. In Belgium, for example, fire fighters wearing SCBA should have a minimum VO_{2max} of 45 ml/kg.min (Kiss et al., 2010).

Aerobic capacity can be measured at either sub maximal or maximal level. Sub maximal aerobic capacity tests, when properly validated, provide an accurate estimation of an individual's oxygen consumption. These tests are less expensive and easier to carry out than maximal tests since they can be performed in a fitness centre by qualified trainers or coaches. Maximal aerobic capacity tests on the other hand, can only be carried out by qualified medical personnel under the supervision of a physician. Testing must be conducted in a medical setting with electrocardiogram (ECG) monitoring, resuscitation and defibrillation equipment on site (International association of Fire Fighters, 2008). However, maximal testing is often preferred because the results are more precise and consistent than sub maximal testing (Dreger et al., 2006; Elsner and Kolkhorst, 2008; Kiss et al., 2010).

A variety of exercise tests can be used in order to determine $VO_{2\ max}$. Several studies emphasize the use of task specific exercise tests because of particular adaptations in the organism to that activity (Ben-Ezra and Verstraete, 1988; Wisløff and Helgerud, 1998). For fire fighters a tread mill or stair mill exercise test is recommended (Ben-Ezra and Verstraete, 1988; International Association of Fire Fighters, 2008). This type of exercise resembles most of the emergency activities of fire fighters. In the case of a maximal test, subjects should complete a continuous, incremental stair mill or tread mill run to exhaustion with continuous monitoring of ECG and oxygen consumption (VO_{2max}).

However, in daily practice many aerobic capacity tests are performed by cardiologists who prefer bicycle ergo meter tests because the electrocardiogram during these tests is more stable and hence shows better ischemic changes than an electrocardiogram during a tread mill test. Treadmill tests are more performed at Sports Medicine centres.

Maximal oxygen consumption depends on age, gender, physical activity, heart rate at maximal exercise, and weight (Fleg et al., 2005; Hawkins and Wiswell, 2003; Kiss et al., 2010; Laukkanen et al., 2009). Furthermore, non-personal factors like the type of test and test centre might influence an individuals' VO_{2max} (Ben-Ezra and Verstraete, 1988; Wisløff and Helgerud, 1998). As the decision to declare a fire fighter fit for his job depends largely on the result of the VO_{2max}, it is important to investigate the relation between $VO_{2\ max,}$ the type of test and the possible influence of the test centre on the outcome.

The purpose of this study was to evaluate the current daily practice of aerobic capacity testing in Belgian fire fighters using data gathered from different field practitioners in different test centres.

It was hypothesized that persons who performed a treadmill test reached a higher $VO_{2\ max}$ than those who performed a bicycle test. During running more muscle groups are involved than during cycling, therefore it can be expected that $VO_{2\ max}$ is higher in tread mill running than in ergometer cycling (Wasserman and Hanssen, 2005). The second hypothesis was that the maximal oxygen uptake varied among the test centres. Test centres use different testing protocols and although it is asked to perform maximal exercise test, centres can differ in the evaluation of maximal exhaustion.

2. Study population and methods

Maximal oxygen uptake ($VO_{2\ max}$) is used for the evaluation of cardio respiratory fitness in Belgian fire fighters. Once a year, fire fighters have a medical examination by their occupational physician. Every five years, the occupational physician refers the fire fighters to a cardiologic or Sports Medicine centre for $VO_{2\ max}$ determination. According to the Belgian guidelines for the medical evaluation of fire fighters, $VO_{2\ max}$ needs to be measured directly, preferably during a maximal stair mill test, if not available during a maximal treadmill test or bicycle ergo meter test.

Since 1999, five occupational physicians of IDEWE, the largest external service for prevention and protection at work in Belgium, gathered 613 $VO_{2\ max}$ results of 605 male and 8 female fire fighters. The tests were performed at 22 different cardiologic or Sports Medicine centres.

Besides $VO_{2\ max,}$ age, gender, body mass index (BMI), waist circumference, type of test (treadmill or bicycle) and medical centre, data on the quality of the performance of the tests such as heart rate at maximal exercise were registered. Maximal oxygen uptake was directly measured during a maximal cardio respiratory exercise test on a treadmill or bicycle ergo meter. As fire fighters were referred to different cardiologic or Sports Medicine centres, different test protocols and measuring equipment were used. The comparison of the heart rate at maximal exercise to the expected maximum heart rate for age (220 beats per minute (bpm) − age) was used as a measure of the quality of the performance of the test (Maximum heart rate percentage = Percentage of maximum heart rate for age at maximal exercise = heart rate at maximal exercise*100/expected maximal heart rate for age).

Since there were only 8 women in the total population, the analysis was confined to the results of 605 male fire fighters who underwent cardio respiratory testing in 22 different cardiologic or Sports Medicine centres in Flanders (the Dutch speaking part of Belgium) from 1999 until 2010.

All statistical analyses were conducted with SPSS 19.0 for Mc Intosh. Analysis of Variance (ANOVA) was used to test for statistically significant differences in continuous variables, chi-square for dichotomous variables. A univariate general linear model was used to detect the determinants and possible interactions that best predicted maximal oxygen uptake. For this model the database was limited to the 6 cardiologic centres that delivered a minimum of 10 cardio respiratory tests, reducing the study population to 564 cases. All important factors and covariates and all their possible interactions were put in the initial model, leaving out one by one the least significant to obtain a model that best predicted the dependent variable.

3. Results

Mean age of the study population was 40.4 years (n = 603, SD = 11.5), ranging between 20 and 60 years. Almost 60 percent was under 45 years of age. Mean $VO_{2\ max}$ was 43.3 ml/kg.min (n = 605, SD = 9.8). Mean $VO_{2\ max}$ according to age, BMI, waist circumference, type of exercise test and maximum heart rate for age (220 bpm − age) attained or not attained according to age is shown in Table 1. Maximal oxygen uptake was statistically significantly dependent of all these variables.

Of the 605 tests performed, 71.1% were treadmill tests, and 28.6% were bicycle tests (for two persons the type of test was unknown). Mean maximal oxygen uptake, age, BMI, waist circumference, and percentage of the maximum heart rate for age at maximal exercise for treadmill and bicycle tests are shown in Table 2. Mean maximal oxygen uptake was statistically significantly different between treadmill and bicycle tests (45.8 ml/kg.min versus 37.3 ml/kg.min). Also age, waist circumference and the mean maximum heart rate percentage were statistically significantly different between treadmill and bicycle tests. Fire fighters who underwent bicycle testing had a lower $VO_{2\ max}$, but they were also