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Original

Aerobic fitness predicts the air consumption time in the self-contained breathing apparatus during physical task of firefighters

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ABSTRACT

Objective: The aerobic fitness on predicting firefighters' air consumption time from self-contained breathing apparatus (T_SCBA) during physical task was investigated.
Methods: Twenty firefighters were divided in two groups: G1 (n=10; 28.0±3.1 years) for the generation of a predictive equation of T_SCBA and G2 (n=10; 25.4±2.3 years) for the validation of the predictive equation. The groups completed two performance tests in separate days: 1) maximal 1600m running in order to determine mean velocity (1600mV) and maximal heart rate; 2) submaximal running/walking at intensity between 88–92% of the maximal heart rate. In second test, the firefighters were equipped with protective clothing (boots, gloves, cape, helmet and balaclava) and the self-contained breathing apparatus. The T_SBCA (corresponding to 1020 liters of pressurized air), blood lactate, heart rate and rate of perceived exertion were measured.
Results: The linear regression of G1 (T_SCBA *vs.* 1600mV) resulted in the following predictive equation: T_SCBA= 0.0442*1600mV (m.min^{-1}) + 4.5029 (r= 0.85; SEE= 0.73; p<0.001). When analyzing in G2, the measured and predicted T_SCBA using the equation generated in G1, no significant differences were found (T_SCBA measured= 15.5±2.5 min *vs.* T_SCBA predicted= 14.7±0.4 min; p=0.21). High correlation (r=0.95; SEE= 0.79; p<0.001) and agreement of the difference of the means (0.9 min [-3.1/+4.8]) were also found.
Conclusion: Aerobic fitness presented high correlation with T_SCBA. In addition, the proposed predictive equation was considered valid to estimate T_SCBA during physical task of firefighters, which can have practical application in the labor activity of this population.
Keywords: Physical fitness, Firefighters, Work.

La capacidad aeróbica predice el tiempo de consumo de aire de un equipo de respiración autónoma durante tareas físicas de bomberos

RESUMEN

Objetivo: Investigar la capacidad aeróbica como factor de predicción del tiempo de consumo de aire de un equipo de respiración autónoma (T_ERA) durante la realización de tareas físicas de bomberos.
Método: Veinte bomberos se dividieron en dos grupos: G1 (n=10; 28.0±3.1 años) para la generación de la ecuación predictiva de T_ERA y G2 (n=10; 25.4±2.3 años) para la validación de la ecuación predictiva. Los grupos completaron dos test en días separados: 1) 1600m de carrera máxima para determinar la velocidad media (1600mV) y la frecuencia cardiaca máxima; 2) carrera submáxima/caminata a una intensidad entre el 88-92% de la frecuencia cardiaca máxima. En el segundo test, los bomberos usaron su ropa de protección (botas, guantes, capa, casco y pasamontañas) y el equipo de respiración autónomo. Se midió: el T_ERA (correspondiente a 1020 litros de aire presurizado), el lactato en sangre, la frecuencia cardiaca y el índice de esfuerzo percibido.
Resultados: La regresión lineal del G1 (T_ERA *vs.* 1600mV) resultó en la siguiente ecuación predictiva: T_ERA= 0.0442*1600mV (m.min^{-1}) + 4.5029 (r= 0.85; EEE= 0.73; p<0.001). Cuando se analizó el G2, no se encontraron diferencias significativas entre el valor de T_ERA medido y el calculado usando la ecuación generada con el G1 (T_ERA medido= 15.5±2.5 min *vs.* T_ERA calculado= 14.7±0.4 min; p=0.21). Se encontró una alta correlación (r=0.95; EEE= 0.79; p<0.001) y concordancia con la diferencia de las medias (0.9 min [-3.1/+4.8]).
Conclusión: La capacidad aeróbica presentó una alta correlación con el T_ERA. Además, la ecuación de predicción propuesta se consideró válida para estimar el T_ERA durante tareas físicas de bomberos, lo que tiene grandes aplicaciones prácticas en la labor de esta población.
Palabras clave: Aptitud física, Bomberos, Trabajo.

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Aptidão aeróbia prediz o tempo de consume de ar no equipamento autônomo de proteção respiratória durante tarefa física de bombeiros

RESUMO

Objetivo: Investigar a aptidão aeróbia na predição do tempo de consumo de ar durante tarefa física de bombeiros a partir do equipamento de proteção respiratória (T_EPR).
Método: Vinte bombeiros foram divididos em dois grupos: G1 (n=10; 28.0±3.1 anos) para geração da equação preditiva do T_EPR e G2 (n=10; 25.4±2.3 anos) para validação da equação preditiva. Os grupos realizaram dois testes de desempenho em dias distintos: 1) 1600m de corrida em máxima intensidade para determinar a velocidade média (Vm1600) e a frequência cardíaca máxima; 2) corrida/caminhada em intensidade submáxima entre 88–92% da frequência cardíaca máxima. No segundo teste, os bombeiros estavam equipados com roupa de proteção (botas, luvas, capa, capacete e balaclava) e equipamento de proteção respiratória. O T_EPR (correspondente a 1020 litros de ar pressurizado), lactate sanguíneo, frequência cardíaca e percepção subjetiva de esforço foram mensurados.
Resultados: A regressão linear do G1 (T_EPR *vs.* Vm1600) resultou na seguinte equação de predição: T_EPR= 0.0442*Vm1600 ($m.min^{-1}$) + 4.5029 (r= 0.85; EPM= 0.73; p<0.001). Quando analizado em G2, o T_EPR medido e predito a partir da equação gerada em G1, não foi encontrada diferença significante (T_EPR medido= 15.5±2.5 min *vs.* T_EPR predito= 14.7±0,4 min; p=0.21). Alta correlação (r=0.95; EPM= 0.79; p<0.001) e concordância na média das diferenças (0.9 min [-3.1/+4.8]) também foi encontrada.
Conclusão: A aptidão aeróbia apresentou alta correlação com o T_EPR. Em adicional, a equação preditiva proposta foi considerada valida em estimar o T_EPR durante tarefa física de bombeiros, o que pode ter aplicação prática na atividade laboral dessa população.
Palavras-chave: Aptidão física, Bombeiros, Trabalho.

Introduction

Rescuing men and women and fighting fires demand performing tasks under adverse environmental conditions, and exerts different physiological stress on firefighters. Emergencies in the interior of large structures, such as underground metro stations or warehouses can lead to prolonged periods of search and rescue, under increased demand on the cardiovascular system in order to provide oxygen to the metabolically active tissues.[1] In extreme environmental conditions, the need to use essential firefighting equipment, including the self-contained breathing apparatus (SCBA), increases the weight of the firefighter in approximately 23 kg.[2] This excessive load augments oxygen uptake during submaximal tasks and reduces the tolerance to performing physical tasks in different intensities.[3,4]

It has been suggested that the SCBA with a capacity of 1360 liters of air can be used by the firefighter for approximately 20min, based on a rate of air release of 50 L/min.[5] Studies performing simulated tasks have shown high variability in pulmonary ventilation depending on the type and intensity of the task.[6-8] Williams-Bell et al.[1] reported that during a search and rescue simulation, firefighters with higher rate of air consumption presented higher peak oxygen uptake when compared to firefighters with a lower rate. In addition, the variations in the rates of air consumption between firefighters could reduce the time needed to consume 75% of the capacity of the cylinder.

When considering that the search and rescue tasks are performed in pairs, firefighters with different pulmonary ventilation can present distinct times of use of the SCBA, forcing a premature withdrawal of the firefighter with more air in the cylinder from the task. In this scenario, investigating associations between physical fitness and time of air consumption in the SCBA (T_SCBA) can aid the strategies of emergency rescues by pairing firefighters with the same air consumption rates.

Due to the great demand of the aerobic metabolism and muscle fitness, laboratory and field tests have been performed aiming to ensure that the firefighters present a satisfactory physical fitness to perform the tasks.[6,9] Aerobic fitness evaluations among firefighters have been performed using direct and indirect estimates of oxygen uptake.[10] The use indirect estimates of aerobic fitness indicators spares the need of high cost equipments and trained personnel, allowing the evaluation of a large number of individuals in short periods of time.[11,12] The development of equations to predict T_SBCA using field tests can help in the strategies of managing air cylinders during an emergency situation. Therefore, the aim of the study was to analyze the usefulness of aerobic fitness on predicting firefighters' T_SCBA during physical tasks.

Methods

Subjects

The participants of the present study were recruited from the 4th Fire Department Corps of Pernambuco/Petrolina-Brazil. The 4th Fire Department Corps was composed by an effective of 130 firefighters. The investigated sample was 20 (15% of population) male volunteers (26.7±3.0 [23.0 to 32.0] years; 78.9±9.8 [62.0 to 104.0] kg; 175.0±6.7 [165 to 190] cm; 25.8±3.0 [21.5 to 32.7] $kg.m^{-2}$). The exclusion criteria were presenting cardiovascular, metabolic, bone, muscle or any other risk factor. Two groups were randomly formed to posterior sample's characterization (G1 and G2), each with 10 participants. The present study was approved by the ethics committee of the Federal University of Vale São Francisco (UNIVASF) (number-5935.0.000.441-10) and all volunteers signed an informed consent form to participate in the study in accordance to the Helsinki Declaration.

Experimental Design

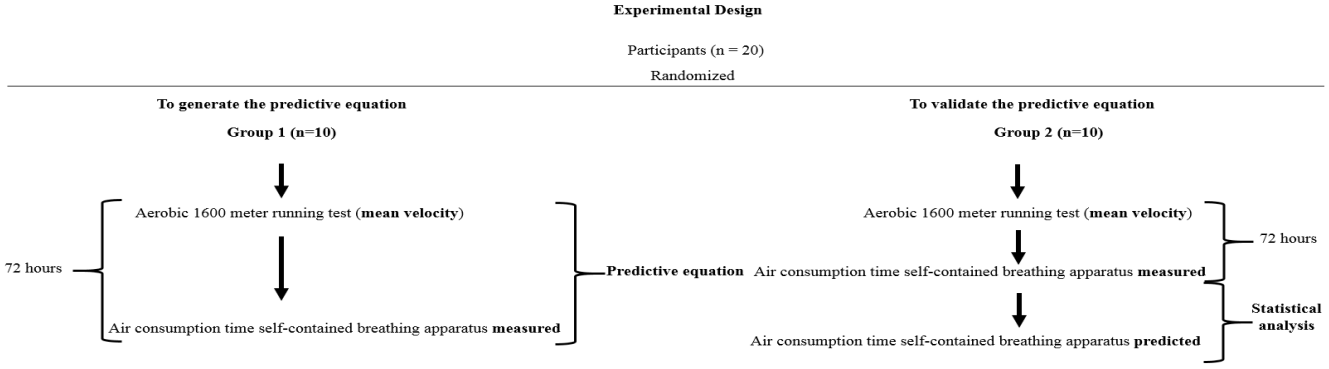
The sample (G1 and G2) performed physical tests in separate days in an official athletics track and the analysis of the variables was performed at the Exercise Physiology Laboratory at UNIVASF, with at least 72h apart (Figure 1).

Test 1: maximal performance in a 1600m running test: The participants were oriented to run 1600m in a 400m athletics track in the lowest time possible. The mean velocity was calculated (1600mV) by dividing the distance by the time in the test. It is important to highlight that tests with absolute measures of performance, such as the 1600m running test, are valid tools for the evaluation of aerobic fitness. The maximal performance in a 1600m test was proposed by the *Rockport Shoes Walking Institute*[11] as an easily applicable field test in different individuals. Other_studies have confirmed its validity in estimating maximal oxygen uptake (VO_2max)[12-15] and maximal blood lactate steady-state (MLSS).[16]

On the other hand, in order to characterize the sample, VO_2max was calculated using the equation proposed by Almeida et al.[15] [VO_2max= (0.177*1600mV) + 8.101] and maximal blood lactate steady-state (MLSS) intensity using the equation proposed by Sotero et al.[16] [MLSS= (0.7507*1600mV) + 21.575]. Moreover, measurements of heart rate (HR) (*Timex*® mod. T5K541F7/TI, Brazil) and rate of perceived exertion (RPE) using a 15 point (from 6/20) scale[17] were performed at the end of the test.

Test 2: submaximal performance test using the Self-Contained Breathing Apparatus: The volunteers were submitted to a

Figure 1. Overview of the experimental procedures.



running/walking test in 400m athletics track at intensity between 88–92% of the maximum heart rate (HRmax) obtained in test 1. This intensity was chosen due to previous studies that showed that firefighters perform their rescuing and firefighting activities at a mean intensity of 90% HRmax.[4,7]

The firefighters performed test 2 wearing their basic firefighting gear (balaclava, boots, gloves, cape, helmet and the SCBA corresponding to 1020 liters of pressurized air - 150 bar in 6.8 liters cylinder). The weight of the gear totaled approximately 23 kg. In this test the participants ran/walked at the above mentioned intensity (90%HRmax) until he consumed 75% of the usable air volume in the SCBA cylinder, which corresponds approximately to 850 liters of air. At this moment, the duration of the test was registered and considered as T_SCBA. The HR of the participant was constantly monitored in test 2 by a heart rate monitor (*Timex*® T5K541F7/TI, Brazil) and by a trained evaluator who followed and gave verbal feedback in order to maintain the intensity of the test (90%HRmax). RPE measurements were performed during the test using a 15 point (from 6/20) scale.[17] In addition, blood lactate ([Lac]) was analyzed (*Accutrend*® Plus, Roche, USA) by collecting 25µL of blood from the participant's ear lobe immediately after the test. RPE and [Lac] measurements in test 2 were performed in order to demonstrate the perceptual and metabolic workload of the physical task using the SCBA.

Statistical Analysis

Data normality was tested using the Shapiro-Wilk's Test. The analysis of the data was performed using descriptive statistics with mean values and standard deviation. Student's t-test for independent samples was used to compare the different variables between G1 and G2. Pearson's linear correlation was performed to verify the association between the studied variables. Linear regression was used in G1 to generate the prediction equation that was applied in G2. Student's paired t-test was adopted in G2 to compare the measured T_SCBA and the predicted T_SCBA. Bland-Altman's technique[18] was used to verify the level of agreement between the measured and predicted T_SCBA. The level of significance adopted was $p < 0.05$ and the software used for analysis was the *IBM SPSS Statistics version* 22.0.

Results

Table 1 presents the main characteristics of the participants and the results obtained in the maximal test (Test 1) and the submaximal test with SCBA (Test 2) in G1 and G2. None of the variables presented statistically significant differences between groups ($p > 0.05$).

The linear regression performed in G1 between T_SCBA and aerobic fitness using the 1600mV resulted in the following equation: T_SCBA = 0.0442*1600mV (m.min^{-1}) + 4.5029 ($r = 0.85$; SEE= 0.73; $p < 0.001$) (Figure 2A).

When comparing, in G2, the directly measured (m) T_SCBA and the T_SCBA predicted (p) by the equation generated in G1 using the 1600mV, no significant differences were found (T_SCBAm = 15.5±2.5 min vs. T_SCBAp.1600mV = 14.7±0.4 min; $p = 0.21$). In addition, there was a high correlation between these variables ($r = 0.95$; SEE= 0.79; $p < 0.001$) (Figure 2B).

The Bland-Altman technique showed that the directly measured (m) T_SCBA agreed with the T_SCBA predicted (p) by the equation generated in G1 using the 1600mV. The mean difference between the values was 0.9 min [-3.1/+4.8] (Figure 2C).

Table 1. Mean (±SD) of main characteristics of the participants in group and results of a maximal aerobic 1600m test (Test 1) and submaximal test with self-contained breathing apparatus (Test 2) in group 1 and group 2.

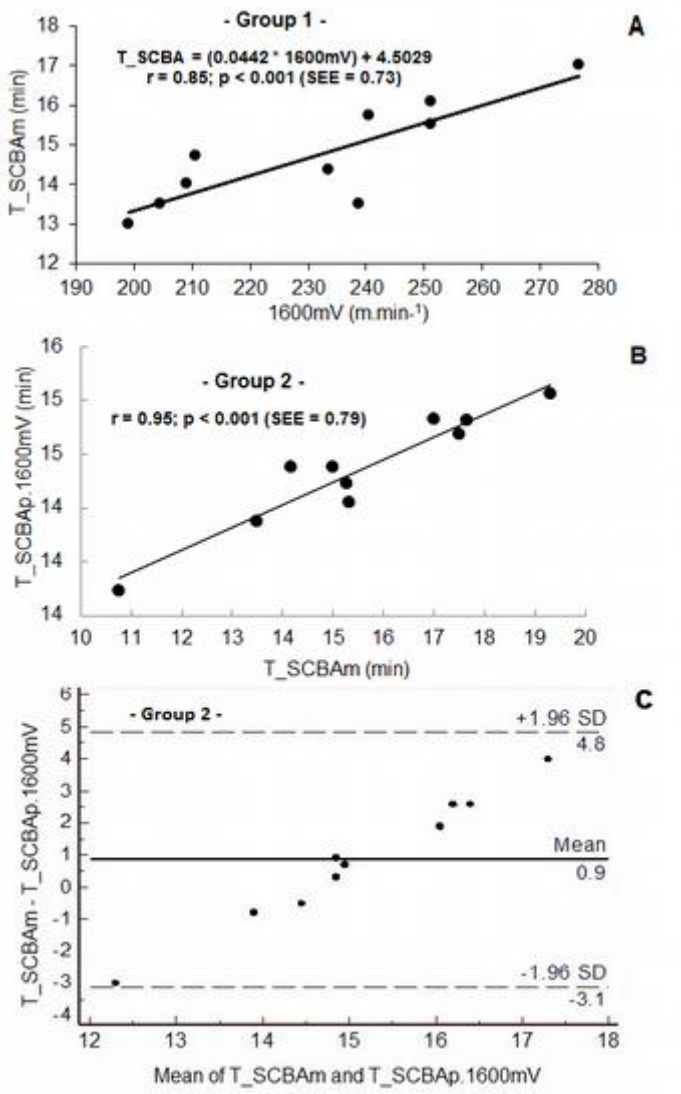
	Group 1 (n=10)	Group 2 (n=10)	*p*
Characteristics of the participants			
Age (years)	28.0 ± 3.1	25.4 ± 2.3	*0.06*
Weight (Kg)	77.6 ± 7.7	80.2 ± 11.9	*0.57*
Height (cm)	174.3 ± 5.1	175.6 ± 8.3	*0.68*
BMI (Kg.m^{-2})	25.6 ± 2.9	26.0 ± 3.2	*0.78*
Test 1			
1600mV (m.min^{-1})	231.6 ± 25.1	230.3 ± 9.8	*0.88*
HRmax (bpm)	190 ± 8	193 ± 6	*0.38*
RPEmax (Borg)	19 ± 1	19 ± 1	*0.57*
VO_2max (mL.kg.min^{-1})	49.1 ± 4.4	48.9 ± 1.7	*0.88*
MLSS (m.min^{-1})	195.4 ± 18.8	194.5 ± 7.4	*0.88*
Test 2			
T_SCBA (min)	14.7 ± 1.3	15.5 ± 2.5	*0.37*
HR-T_SCBA (bpm)	169 ± 9	171 ± 7	*0.74*
T_SCBA (%HRmax)	88.9 ± 2.5	88.3 ± 3.6	*0.67*
RPE-T_SCBA (Borg)	13 ± 2	13 ± 1	*0.31*
Lactate-T_SCBA (mM)	5.1 ± 1.9	5.0 ± 1.4	*0.83*

BMI: Body mass index. 1600mV: Mean velocity in the 1600 meters running test; HRmax: Maximal heart rate obtained in 1600 meters running test; RPEmax: Maximal rate perceived exertion obtained in 1600 running meters test; VO_2max: Maximal oxygen uptake; MLSS: Running velocity associated to the maximal blood lactate steady state; T_SCBA: Air consumption time in the self-contained breathing apparatus; HR-T_SCBA: Heart rate during the submaximal test with self-contained breathing apparatus; %HRmax: Percentage of HRmax; RPE-T_SCBA: Rate perceived exertion during the submaximal test with self-contained breathing apparatus; Lactate-T_SCBA: Blood lactate during the submaximal test with self-contained breathing apparatus.

Discussion

The main finding of the present study was that aerobic fitness, measured through a maximum 1600m running performance, presented high correlation with T_SCBA (Figure 2A) and that the equation proposed was valid in estimating T_SCBA during physical tasks in firefighters (Figure 2BC). To our knowledge, this is the first study to investigate an association between aerobic fitness and T_SCBA, as well as the prediction of this last variable by an indicator of aerobic fitness in firefighters that perform physical tasks at intensities close to 90% HRmax.[7] The experimental design proposed using a cross validation method of the equation (Figure 1) allowed the identification of the main finding of the study and the confirmation of the implicit hypothesis of the study.

Figure 2. (**A)** Linear regression and equation generated in group 1 between air consumption time in the self-contained breathing apparatus directly measured (T_SCBAm) and mean velocity in the 1600m running test (1600mV); (**B)** Correlation in group 2 between T_SCBAm and predicted by 1600mV (T_SCBAp.1600mV); (**C)** Agreement (Bland-Altman) in group 2 between T_SCBAm and T_SCBAp.1600mV.



The prediction of T_SCBA can be very important for the efficacy of the work performed by the firefighter when fighting fires, chemical emergencies or in rescue situations in adverse environmental conditions.[9,10] Based on the suggested predictive model, the firefighter will have more knowledge about his/her potential when performing his/her work. In addition, the firefighter will know more about the physiological parameters related to the efforts performed at work, which can stimulate the pursuit of a better physical fitness and, thus, more economy when it comes to air consumption while attending simulations or emergencies. The knowledge about these parameters can also increment the management of the human and material resources during a situation where SCBAs are needed. Another aspect that must be highlighted regards the fact that firefighters act in pairs. Thus, the predictive equation of T_SCBA can serve as a tool for better pairing firefighters with the intent of avoiding a premature withdrawal of the action due to faster air consumption by one of them.

It is known that, during a firefighter's training course, it is considered that the volume of air present in the SCBA allows the equipment to work for approximately 27min.[5] However, in the present study, the results showed that the T_SCBA lasted approximately 15min (Table 1). This reflects in an overestimation of the initially preconized time and, therefore, the possibility of compromising the efficacy of the work during an emergency, as well as the management of human and material resources. One possible explanation to this overestimation could be not considering the variations in aerobic fitness that occurs from one individual to another. That is according to the concept of cardiovascular efficiency and economy,[19] puts an individual with better physical fitness with a higher T_SCBA, as it is evidenced in the present study.

The practical applications of the present study involve the generated and validated equation to estimate T_SCBA [T_SCBA= 0.0442*1600mV ($m.min^{-1}$) + 4.5029] during physical task in firefighters. The present equation can be using after performing a maximal performance 1600m running test,[13,14] and thus, calculating the mean velocity achieved in the test (1600mV). The prediction of T_SCBA can be useful as a tool for better pairing firefighters and better managing human and material resources while performing emergency procedures. In addition, as it is evidenced by previous studies from our research group, while evaluating the 1600m running performance it is also possible to predict the VO_2max[15] and the running velocity associated to the MLSS[16] what, in turn, may be useful for individualized training prescriptions leading to improved aerobic fitness and thus increasing the T_SCBA in firefighters.

Moreover, the sample of firefighters in the present study presented a VO_2max of 49.1±4.4 and 48.9±1.7 $mL.kg.min^{-1}$ for G1 and G2, respectively, as well as a MLSS speed of 195.4±18.8 and 194.5±7.4 $m.min^{-1}$ correspondingly. Other authors,[10] studying Swedish firefighters (34.0±9.8 years) found VO_2max of 55.0±5.9 $mL.kg.min^{-1}$ and MLSS of 193.3±31.6 $m.min^{-1}$. Although aerobic power was slightly lower in Brazilian firefighters, there are similarities in aerobic capacity (MLSS), which suggest speculating that there are different demands in the aerobic training of firefighters from different countries. Lindberg et al.[10] demonstrated that VO_2max of Swedish firefighters are significantly correlated to different tasks related to firefighter's laboral activities (cutting, climbing, pulling, demolishing, rescuing and working in different terrains). This corroborates with the present study, where VO_2max was estimated from a 1600m running test[15] and significant correlations with capability of discriminating T_SCBA of Brazilian firefighters were found.

An aspect to be considered in the present study regards the agreement analysis and the dispersion of the results (Figure 2C). It is possible to observe: i) that the higher the firefighter's T_SCBA, the more the equation tends to underestimate its real value, while the lower the firefighter's T_SCBA, the more the equation tends to overestimate its real value and; ii) as the means of both tests increases, the difference between them also increases, which suggests heteroscedasticity of the results. Although this can be considered as a limitation, the same condition can be acknowledged as a positive factor of the present study, since it contributes once more to the importance of rightfully pairing the firefighters during an emergency.

Other limitations that are worth highlighting involve: 1) number of participants in the present study, which, even though represents 15% of the total population of the Corps, could be questioned due to the statistical procedures used and; 2) the lack of performing a repeatable test of Test 2. Both aspect suggest caution when interpreting the results and future studies involving the topic are encouraged aiming to guarantee more robust results.

We conclude that aerobic fitness, measured through a maximal performance 1600m running test, is highly correlated with T_SCBA. In addition, the proposed equation may be of practical application once it can provide a valid estimate of T_SCBA during physical task in firefighters that have similar characteristics to the ones of the present study. New studies with firefighters with different characteristics (age, sex, physical fitness levels) and with

different protocols that reproduce real firefighting environments are encouraged, with the purpose of contributing to confirm the association between aerobic fitness and T_SCBA.

Authotship. All the authors have intellectually contributed to the development of the study, assume responsibility for its content and also agree with the definitive version of the article. **Provenance and peer review.** Not commissioned; externally peer reviewed. **Ethical Responsabilities.** *Protection of individuals and animals:* The authors declare that the conducted procedures met the ethical standards of the responsible committee on human experimentation of the World Medical Association and the Declaration of Helsinki . *Confidentiality:* The authors are responsible for following the protocols established by their respective healthcare centers for accessing data from medical records for performing this type of publication in order to conduct research/dissemination for the community. *Privacy:* The authors declare no patient data appear in this article.

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