COMPARATIVE EVALUATION OF DIFFERENT TYPES OF SELF-CONTAINED BREATHING APPARATUS

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INTRODUCTION AND OBJECTIVES

During their regular exercises, firefighters reveal physiological reactions that might be hazardous for health as heart rates may increase to more than 200 beats per minute and rectal temperatures to more than 41°C (1,2). These observations are matter of concern particularly in view of the fact that real firefighting actions might be much more strenuous.

Due to their weights, self-contained breathing apparatuses (SCBAs) contribute considerably to the overall strain (3). Accordingly, lighter SCBA are expected to reduce the strain, and as the loads of the SCBA weigh primarily on the shoulders, improvements are also likely with better distributed loads. In this study, a recently developed SCBA with an innovative rucksack-shape (Device C) was compared with two conventional cylindrically shaped SCBAs (Devices A, B). Criteria were the physiological strain during the exercises and subjective evaluation of the SCBA.

MATERIALS AND METHODS

Subjects clothing: Twelve experienced firefighters (27 to 49 yrs, 172 to 193 cm, 71 to 84 kg, 2.8 to 4.6 L.min-1,) volunteered, wearing stan-dardized clothing (t-shirt, pants, socks, 2-piece permeable protective suit; esti-mated insulation of about 1 clo). The study was approved by the local Ethics Committee.

SCBA: Device A (PA 80) is normally used in real firefighting actions. Its conventional cylindrical container consists of steel, its volume is 6 L, its filling pressure 300 bar, and its total weight is 15 kg (including backplate and belts). The Device B (DrägerMan PSS 100), which is also cylindrically shaped, is greater (6.8 L) but weighs--due to carbon fiber composite material instead of steel--only 11.7 kg, the filling pressure is 300 bar. Device C (DrägerMan PSS 500) consists of 3 spherical carbon fiber composite containers with a volume of 2 L each that are arranged in a triangle and installed in an accordingly larger-shaped container (rucksack) thus optimizing weight distribution on the wearer's body. Its total weight is 13.7 kg, and the pressure is 300 bar.

Standardized exercises: Exercises consisted of simulated rescue work on the 2nd floor (Part 1) and several typical elements of severe firefighting actions (Part 2) and were followed by a 10-min recovery period. They were executed on 3 non-consecutive days. The 3 SCBAs were used in a systematically permuted sequence.

Physiological parameters and subjective evaluation: Because exercise time was not limited, the durations indicate performance. Heart rates (HR) calculated fi-om the electrocardiogram and rectal temperatures (Tre) measured with thermistors (YSI 401; Yellow Springs) at a depth of 10 cm were continuously recorded. Sweat production **(SP)** was determined by weighing the nude subjects before the exercise and after recovery (accuracy ± 1 g). After the exercise, the subjects completed a questionnaire concerning the carrying features of the SCBA during standing, walking, running, creeping, crawling (backwards), bending and stretching.

Statistics: A 2-factorial ANOVA for repeated measures was applied to proof the influence of the SCBA considering the permutation sequence. Calculations were done with SAS', version 6.12; $P < 0.05$ was regarded as significant.

RESULTS

Climatic conditions: Air temperatures and humidities varied as follows: 17.4 to 19.2°C and 59`to **80%** in **Part** 1 (flat), 23 to 25°C and 43 to 57% in **Part 2** (exercise), 11 to 16°C and 50 to 94% outdoors.

Physiological and subjective variables: Figure 1 shows HR and Tre for a single subject during his 3 exercises with the 3 devices. The courses of the physiological data are typical for all subjects. HR increased during **Part** 1, first steeply while climbing the stairs, then moderately until leaving the flat to almost 170 bpm. After a transient decrease of about 25 bpm when descending, HR increased again during **Part 2** up to 170 to 180 bpm. When retreating to the preparatory room, HR decreased gradually and reached a steady state within the first **5** min of recovery. The means over the entire exercise, over **Parts** 1 and 2 were 160.2 ± 15.0, 155.3 ± 16.1 and 167.4 ± 14.3 bpm, respectively. Tre increased continuously during the

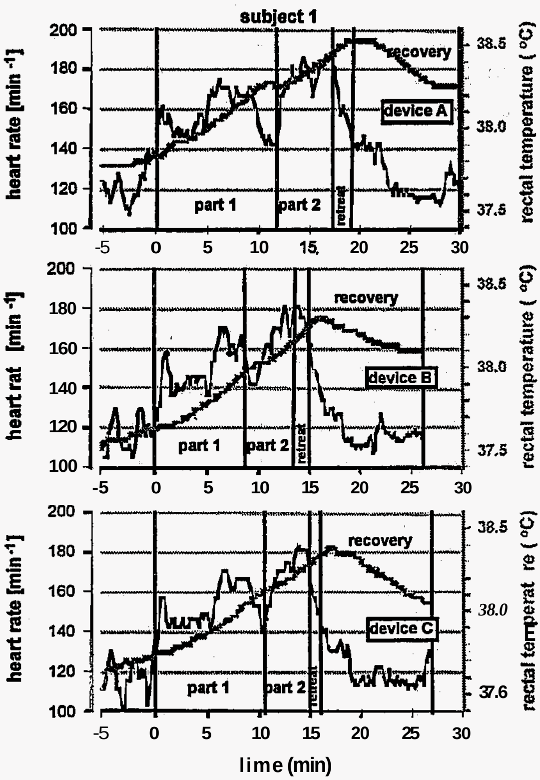

Figure 1. Heart rates and rectal temperature during exercises

exercise and reached its maximum (38.4 ± 0.2°C) during the 3rd to 4th min of the recovery period and then decreased gradually. Average SP was 377 ± 91 g. The mean durations needed for the entire exercise, for Part 1 and Part **2** were 14.6 ± 2.1 min, 8.3 ± 1.6 and 6.2 ± 0.8 min, respectively.

Comparison of the 3 SCBA SP and Tre did not vary with the type of device. Significant differences were found for duration, HR and subjective evaluation. The time needed for Part 2 was shortest with Device C (Fig. 2). Compared to Device A, the shortening was 40 s, in particular cases even up to 2 min. HRs were significantly lowest with Device C during Part 1. All of the items in the questionnaire revealed a better evaluation of Devices B and C than for Device A ($P < 0.01$). Regarding the upright posture, there were no differences between Devices B and C, except for bending and torsion movements, Device C was significantly better than Device B ($P < 0.01$).

DISCUSSION

A recently developed SCBA with an innovative rucksack-shape causing a better distribution of its weight over the middle and lower parts of the back

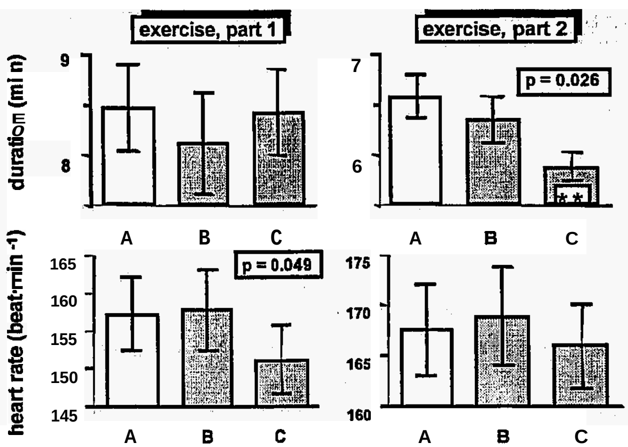

Figure **2:** Duration and heart rates during exercises, means and standard deviations

(Device C) was compared with two conventional cylindrically shaped SCBAs. The latter differed from each other with respect to volume and weight (A 6L, 15kg; B: 6.8L, 11.7kg). The comparison was based on standardized exercises that comprised several typical tasks of real firefighting actions. The rather cool environment corresponds to the usual training conditions.

Based on former studies (3), lower HRs were expected with lighter SCBA. Though the firefighters rated Devices B and C as better than the currently used Device A, a decrease in physiological strain and improvements in performance (faster execution of the exercise) was only observed with the rucksack device. Despite its lower weight, the physiological strain observed when using Device B was not less than with Device A. This is probably due to its larger volume (6.8 L), which makes it more difficult to pass through and to turn in low and narrow spaces. For a SCBA of 6 L, the use of carbon fiber composite material might lead to a greater reduction of the weight and strain. Such a devel-opment is recommended as previous studies have shown that rectal temperatures increased to critical values during 25 min, which corresponds to a supply of 6 L (4,5). So, SCBAs with greater volumes should be used only in exceptional situations.

Though Device C weighed only 1.3 kg less than Device A, the physio-logical strain--as indicated by the HR--was significantly lower than with the other devices (A, B) during Part 1. So, probably due to enough reserves, Part 2 was completed faster than with Devices A and B.

CONCLUSIONS

The significantly lower cardiac strain for similar performance times associated with the use of Device C cannot be explained by the lower weight but by its ergonomically favorable distribution over the middle and lower back that allows a better mobility than the conventional cylindrically shaped devices. The results of this study lead to the conclusion that within the limits studied here and with respect to subjective evaluation, physiological strain and performance, the reduction of the weight is less important than its distribution.

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