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Energy Cost of the Trondheim Firefighter Test for Experienced Firefighters

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Aim. *The aim of this study was to measure aerobic demands of fire fighting activities including exercise in the heat.* ***Methods.*** *Twenty-two experienced firefighters performed the Trondheim test simulating fire fighting tasks including work in the heat. Maximal oxygen uptake ($V_{O2\,max}$), heart rate (HR) and ventilation were recorded continuously. Data were compared with results obtained during a treadmill test during which the participants were dressed as smoke divers.* ***Results.*** *The participants completed physical parts of the Trondheim test in ~12 min (range: 7.5–17.4). Time to complete the test was closely related to the participant's $V_{O2\,max}$. HR of ~170 beats/min and pulmonary ventilation of ~100 L/min were higher than at lactate threshold (LT) during laboratory tests. V_{O2} averaged over the test's physical part was 35 ± 7 ml/min/kg, which was at the same or below the level corresponding to the participants' LT. Physically fit participants completed the test faster than less fit participants. Slower and physically less fit participants consumed more air and used more oxygen than faster and physically more fit participants.* ***Conclusion.*** *The Trondheim test is physically demanding; it distinguishes physically fit and less fit participants.*

blood lactate concentration   fire fighting   maximal oxygen uptake   lactate threshold
pulmonary ventilation   rating of perceived exertion

1. INTRODUCTION

Fire fighting involves strenuous physical activities. Firefighters must move around, perform activities including vertical ascents; handle heavy equipment, e.g., drag, pull or carry a firehose; and they must also be able to assist or to carry victims unable to rescue themselves. Firefighters wear protecting clothing that weighs ~10 kg to protect themselves against fire or other danger. Moreover, in the Nordic countries, firefighters are often dressed as smoke divers to protect themselves against hazardous gases. This extra equipment weighs 11–18 kg, depending on the type of self-contained breathing apparatus (SCBA) used. Thus, the total protective equipment carried might weigh 20–30 kg; the mass of fire fighting tools is not included. Furthermore, breathing in from SCBA may provide an additional restriction since the breathing resistance at high ventilations may be considerably higher than that of breathing free air or through modern metabolic analysers [1, 2]; this may reduce maximal oxygen uptake ($V_{O2\,max}$) by over 10% [3, 4, 5].

We thank Lisbeth Andersen, head of the education programs at the Trondheim fire brigade, for her support in carrying out the experiments. We appreciate the technical skills of Steinar Messel and Ole Synnes at the work-shop of the National Institute of Occupational Health who made connections between the Interspiro face mask (SM) and electronics producing an inspiration signal after each expiration (OS), and further to Morten von Heimburg at Nord-Trøndelag University College who made a heat-proof box for the MetaMax II.

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Fire fighting and rescue work may be very demanding for the cardiorespiratory system [6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28]. However, all these studies have some limitations in examining physical demands of real fire fighting. Some studies provide only indirect measures of aerobic demand like heart rate (HR) or air consumption during exercises [7, 10, 13, 15, 23, 28, 29]. Oxygen uptake (V_{O2}) has also been measured during fire fighting tasks [6, 8, 9, 11, 12, 17, 18, 19, 20, 21, 24, 25, 26]. This is important since the relationship between HR and V_{O2} may differ considerably between exercise on ergometers (treadmill) and during fire fighting tasks [9]. In other studies, participants inhaled from SCBA using face masks and breathing valves of smoke divers [5, 30]; this simulates real fire fighting tasks. However, there are no studies on V_{O2} during fire fighting tasks in the heat with participants breathing in from SCBA, possibly because heat may damage delicate instruments like metabolic analysers [19, 26]. Moreover, intensive exercise may involve anaerobic energy release and, thus, lactic acidosis may increase ventilation more than that required by the raised V_{O2}. Few studies have measured blood lactate concentration. Information on pulmonary ventilation and air consumption is also limited. Focusing on a limited number of tasks is another limitation in many studies, since real fire fighting includes many different tasks.

The Trondheim fire brigade (Norway) developed a test with fire fighting tasks including work in the heat; exercise in the heat gives an extra aspect of simulated fire fighting not found in former studies. It has been shown that realistic rescue work may tax the aerobic system maximally [17]; however, this has not yet been proved with the Trondheim test. O_2 demand of the test is not known, and there is no information on possible differences between fit and less fit firefighters.

Results of former studies suggest that time needed to perform specific fire fighting tasks may depend on the level of aerobic fitness of firefighters [17, 18, 20, 25, 31]. Traditionally, $V_{O2\,max}$ and lactate threshold (LT) measured during standard treadmill running have been used as measures of aerobic fitness. Results of such tests have limited value in predicting performance during simulated fire fighting or rescue tasks [9, 17, 32, 33]. Laboratory tests should be modified so that participants' $V_{O2\,max}$ and LT are measured during walking on the treadmill dressed as firefighters, thus, including extra demand caused by the firefighters' garment and equipment. In this study, the participants' $V_{O2\,max}$ and LT were measured during treadmill walking; the participants were dressed as smoke divers.

We hypothesised that the Trondheim test is physically demanding and requires high V_{O2}. Consequently, it was hypothesised that performance on the test (time to completion) would be closely related to the participants' aerobic fitness level.

2. METHODS

2.1. Overall Design and Approach to Problem

All participants of the study carried out the Trondheim test. On separate days, the participants' $V_{O2\,max}$ and LT were measured during treadmill walking; the participants were dressed as smoke divers [34]. The tests were carried out at least 2 days apart to allow proper recovery; all tests were completed within 2 weeks.

The Trondheim test, described in section 2.3.1, was carried out at a local fire station; indoors and outdoors (part 1 and 3, respectively), and in the heat chamber (part 2). The standard test includes dressing and undressing at the start and the end, respectively, and solving a simple puzzle. Because this study focused on physical demands of the test, these parts were not included in the results. The treadmill tests were conducted in the laboratory. The equipment had to be modified and protected to allow measuring V_{O2} in the heat [35].

2.2. Participants

The study involved 22 professional firefighters (21 men, 1 woman) from the Trondheim fire brigade (Table 1). The participants knew the test, and each participant had earlier completed the Trondheim test 8 ± 3 times (*M* ± *SD*). The participants were informed about the study's purpose and its details both orally and in writing before they gave their written consent. The participants were volunteers and were allowed to leave the study at any stage without giving a reason. The Ethics Committee of Health Region 4 in Norway approved the study.

TABLE 1. Characteristics of Participants

Parameter	Men (n = 21)	Women (*n* = 1)
Age (years)	42 ± 9	26
Height (cm)	1.82 ± 0.05	1.69
Body mass (kg)	85 ± 9	58
Body fat (% of body mass)	23 ± 6	16
Lean body mass (kg)	66 ± 6	49
BMI (kg/m^2)	26 ± 2	20.3
BFI (kg/m^3)	14.1 ± 1.5	12.0
Waist/hip circumference ratio	0.94 ± 0.05	0.83

Notes. Data for men are $M \pm SD$. BMI = body mass index, BFI = body frame or pondal index taken as the body mass divided by the cube of the height. Body fat has been calculated from measurements of four skin fold thicknesses [37].

2.3. Procedures

The participants avoided strenuous physical activity and did not smoke or consume alcohol the day before the tests, and they did not eat less than 3 h before the tests.

2.3.1. Trondheim firefighter test

The Trondheim test is an applied firefighter test; that includes several fire fighting tasks. The test has been used by the Trondheim fire brigade for over 10 years. Before the test, the participants dressed as smoke divers, they had heat protective clothing, SCBA with a face mask and compressed air bottles. The protective equipment, including SCBA, weighed ~28 kg. In the present study, the participants also wore a portable metabolic analyser, MetaMax II (Cortex Biophysik, Germany), which measured V_{O2} during the test. The analyser was placed in a protective box; the box and the analyser weighed ~4 kg. The box was mounted on SCBA on the back of the firefighter. During a normal test, the participant inhaled from the SCBA and expired to the atmosphere. In this study, air was expired through the metabolic analyser.

The Trondheim firefighter test consisted of the following parts and tasks:

- The firefighter dressed up.
- Part 1: "emergency"
  - *Puzzle.* The participant walked 5 m from the start to a table (0.5 m high) to solve a small puzzle of 20 pieces (suitable for a 5–7-year-old child). After solving the puzzle, it was dismounted. Then, the participant walked 2.5 m to the next task.
  - *Balance.* The participant walked on a 4-m-long and 10-cm-wide beam placed 35 cm above the floor. If the participants fell down, they had to return to the beginning of the beam and repeat the walk. Then, the participant walked 13 m to the next task.
  - *Hose dragging.* The participant carried, over the preferred shoulder, a 5-m-long firehose filled with sand to a total mass of 32 kg (nozzle 3.3 kg) for 58 m. The task included stair climbing (one floor up and one floor down). The coefficient of friction between the entire hose and the floor was ~0.5. Then, the participant walked 8 m to the next task.
  - *Hose connection and disconnection.* The participant had to connect five pairs of firehoses and disconnect another five pairs. Then, the participant walked 5.5 m to the next task.
  - *Carrying heavy cans (rescue work simulation).* The participants carried four cans, 23 kg each, for 11 m. The participant carried two cans at the same time. Then, the participant walked 6 m to the next task.
  - *Tunnel crawling.* The participant crawled through a 2-m-long tunnel with a diameter of 60 cm.
  - Then, the participant walked 58 m to the heat chamber.
- Part 2: heat chamber
  The participant did physical work in the heat chamber kept at 120–140 °C by burning natural gas. The participant carried 10 concrete blocks, 18 kg each, up seven steps, each 18 cm high, giving a vertical ascent of 1.26 m; then,

the participant brought down 10 other blocks. Half of the blocks hung on hooks ~0.8 m above the floor, while the other half hung on hooks ~1.85 m above the floor. The total distance walked in the heat chamber was ~210 m.

- Part 3: "retreat"
  The tasks of part 1 were performed in the opposite order, ending with solving and dismounting the same puzzle as at the beginning of the test. Then, the participant walked 5 m to finish the test.
- The firefighter undressed.

Modifications for this study

The MetaMax II was mounted to SCBA after the participant got dressed. Because this study focused on V_{O2} and related parameters during the physical part of the test, dressing and undressing, and solving the puzzle were not included as they were not physically demanding. Consequently, the test started when the participant started the balance task, and it ended when the participant finished the final balance task. The firefighter with the protective box with the MetaMax II could not crawl through the tunnel with a diameter of 60 cm. Consequently, the participant crawled under a garage door raised so the lower edge was ~65 cm above the floor.

The total distance walked during the test was ~582 m; the test had to be completed as quickly as possible. The total time and the time for each task were recorded. The main performance time for this study was the time needed for all physical tasks (all tasks except solving the puzzles).

After the test, a blood sample was taken to measure blood lactate concentration. The rating of perceived exertion (RPE) was recorded with the Borg CR10 scale [36]. The thermal sensation was also recorded.

2.3.2. $V_{O2\,max}$

$V_{O2\,max}$ was measured during an extended version of the treadmill test for examining firefighters' aerobic ability approved by the Norwegian Labor Inspection Authority (NLIA). The firefighter was dressed as a smoke diver (standard protective equipment including a fireproof jacket and pants, and isolating underwear). During the treadmill test (NLIA treadmill test), jogging shoes replaced the standard protective boots to avoid overloading the Achilles tendon. The firefighter did not wear a helmet or a face mask. The firefighter wore a backpack harness with SCBA, but the firefighter breathed in indoor air instead of the air from the SCBA. The whole outfit had to weigh 23 kg; if light-weight SCBA was used, additional weigh was added with sand bags. The treadmill speed of 1.56 m/s (5.6 km/h) was fixed. During the first and the second minute, which were a quick warm-up, the treadmill inclination was 4% and 7%, respectively. After 2 min of exercise, the inclination was raised to 12% and kept for the next 6 min. After 8 min of exercise, which is the end of the standard NLIA treadmill test, the treadmill inclination was raised to 14% and kept so for the rest of the test. If the participant was able to continue the exercise after 9 min of walking, the speed was increased by 0.056 m/s (0.2 km/h) every minute until exhaustion. V_{O2} was measured throughout the test, and the highest value obtained was taken as the participant's $V_{O2\,max}$.

2.3.3. Lactate threshold

The participants were dressed like for the extended NLIA treadmill test (the whole outfit weighed 23 kg). The test protocol of 5-min steps was used. The treadmill speed was set at 1.56 m/s (5.6 km/h), the inclination was 0%. After 5 min of exercise and a 1-min break for measuring the blood lactate concentration, the inclination was raised by 2% and kept for the next 5 min. After another 1-min break, the inclination was raised by 2%. This procedure was repeated until the blood lactate concentration was over 4 mmol/L. When the maximal treadmill inclination was 14%, the speed was increased by 0.08 m/s (0.3 km/h) every 5 min. V_{O2} and HR were recorded throughout the walk; steady state values recorded near the end of each step were used in this study.

An inclination of 0% allowed testing the unfit participants, while the fit participants could perform the test at higher exercise intensities. Thus, on the basis of the results from previous tests (Trondheim test and $V_{O2\,max}$ test) and the experience from former experiments, the intensity of the first step was chosen individually. Consequently, each participant did only 4–6 steps. V_{O2} and HR corresponding to onset of blood lactate accumulation (OBLA) were obtained by linear interpolation between the two measurements most closely under and over 4 mmol/L [34].

2.3.4. Anthropometric measurements

The body mass was measured with a digital scale (Heine, Germany), the stature was also measured. Each participant's body fatness was calculated by measuring four skinfolds with a Harpenden skinfold caliper (John Bull, British Indicators, UK). Skinfolds were measured at four different places: m. biceps brachii and m. triceps brachii (midway between shoulder and elbow joints), subscapular skin fold and supra-iliac skin fold. The proportion of body fat was measured according to the Durnin and Womersley skinfold equation [37].

2.4. Instruments

V_{O2} and pulmonary ventilation were measured with MetaMax II. The MetaMax II has been validated separately [38, 39]. During the measurements the instrument recorded data in 10-s intervals with no further averaging or delaying beyond the built-in hardware. The instrument was calibrated in the morning and before the start of each experiment according to the instruction manual.

The MetaMax II analyser is a low-weight, delicate instrument that does not tolerate high temperatures or hard mechanical contact. Therefore, to protect the instrument against heat and mechanical impacts, it was placed in a wooden box filled with an isolating material (mineral fibre; Protecta, Norway). The lines connecting the main unit and the instrument's Triple V sensor, normally mounted on a face mask, were isolated with a wool stocking tube, covered with the same cotton used in firefighters' protective clothing, and with fiber tape as outer cover. The fiber tape was inspected after each experiment and replaced when needed. Parallel measurements showed that even after 8 min in the heat chamber, the temperature in the box never exceeded 25 °C, and the temperature inside the stocking tube was kept below 40 °C.

During regular work at the scene of fire, a smoke diver breathes in from SCBA worn on the back to avoid breathing in contaminated air; they breathe out to the atmosphere. The air inside the heat chamber was contaminated and might be hazardous for the participants and the metabolic analyser. To avoid breathing in polluted and hot air for the MetaMax II recordings, the Triple V of the MetaMax II was mounted to the outlet of the face mask (Interspiro, Sweden). The connections between the Triple V and the face mask were made at the National Institute of Occupational Health, Oslo, Norway. Only the air breathed out by the firefighter passed through the instrument. Although the MetaMax II only analyses expired air, the instrument required an inspiration signal between two expirations to work properly. Therefore, the instrument was modified so that an artificial inspiration signal was made and sent to the main unit after each expiration [35].

HR was measured with a heart rate monitor Polar Accurex Plus PE 3000 (Polar Electro, Finland) set to register at 15-s intervals. The blood lactate concentration was measured with a portable 1710 Lactate Pro analyser (Arkray, Japan). This analyser needed a 5-μl blood sample. The instrument has been evaluated separately; it is accurate, reliable and suitable for field experiments [40]. The RPE was recorded with the Borg CR10 scale [36]. The thermal sensation was recorded on a 0–5 scale (*neutral* = 0, *slightly warm* = 1, *warm* = 2, *hot* = 3, *very hot* = 4, *extremely/intolerably hot* = 5); scores 4 and 5 were added to the scale prepared for other studies [41]. Negative values describing cold sensation on the original scale were not analysed in this study.

Treadmill exercises were performed on a Trotter 645 treadmill (Cybex International, USA). The readings of inclination and speed were controlled with separate calibrations.

2.5. Data Handling

The highest V_{O2}, peak pulmonary ventilation and peak HR at the Trondheim test and the extended NLIA treadmill test were taken as the median of three successive highest recordings.

Three participants did not finish the 8-min NLIA treadmill test, and their peak V_{O2} were conspicuously low. To estimate reliably their $V_{O2\,max}$, the linear relationship between HR and V_{O2} during the LT test was extrapolated to peak HR obtained in the Trondheim test; corresponding V_{O2} was used as their maximum values.

2.5.1. Statistics

The results of the Trondheim test versus $V_{O2\,max}$ and OBLA results were related with standard univariate least square linear regression. The regression error was the main parameter assessing the goodness of the fit. Pearson product-moment correlation coefficient was also used. The data were summarized as *M* ± *SD*.

3. RESULTS

3.1. Laboratory Tests

During the extended NLIA test, the firefighters walked for 13 ± 5 min (range: 4–19; 11 for a female). During the final stage, the firefighter's average walking speed was 1.78 m/s (6.4 km/h) at an inclination of 14%; every firefighter carried 23 kg. HR rose to 182 ± 11 beats/min at the end of the test. Peak V_{O2} at the end of the test was 52 ± 10 ml/min/kg (range: 31–67; 56 for female), which corresponded to 40 ± 7 ml/min/kg total mass carried (including 23-kg outfit). Values of peak V_{O2} were used as the firefighters' $V_{O2\,max}$, during walking in a smoke diver outfit, and the values have been compared with V_{O2} during the Trondheim test (see below).

During the OBLA test, the firefighters walked on the treadmill at incremental exercise intensity; at the same time V_{O2}, HR and blood lactate concentration were recorded. When the blood lactate concentration reached 4 mmol/L, HR was 166 ± 14 beats/min (16 ± 7 beats/min under the maximum value). V_{O2} at OBLA was 41 ± 6 ml/min/kg (31 ± 5 ml/min/kg total mass carried), which was 78 ± 5% of $V_{O2\,max}$.

3.2. Trondheim Test

All firefighters completed the physical part of the Trondheim test in 12.0 ± 3.0 min (range: 7.5–17.4; 15.8 for female). The firefighters spent 5.5 ± 1.6 min (range: 3.4–8.3; 8.0 for female) in the heat chamber. Performance time differed considerably between the participants; faster participants completed all tasks faster than the slower participants.

3.2.1. Time course of physiological parameters

HR increased quickly at the beginning of the test and remained high at 170 ± 10 beats/min throughout the physical part of the test (Figure 1). Consequently, HR was at or over the value corresponding to LT. Peak HR of 184 ± 10 beats/min for most firefighters observed during the second firehose dragging, did not differ from the maximum values recorded during the extended NLIA test.

Pulmonary ventilation increased quickly and was 85 ± 13 L/min throughout the physical part of the test. Peak ventilation of 107 ± 19 L/min was recorded during tasks in the heat chamber and remained at the same level during part 3 of the test (Figure 1). The average pulmonary ventilation was above the level corresponding to ventilation at LT during the treadmill test; however, the value during the Trondheim test was considerably below peak ventilation observed during measuring $V_{O2\,max}$.

Average V_{O2} during the physical part of the test was 35 ± 7 ml/min/kg (36 ml/min/kg for female); 25 ± 4 ml/min/kg total mass carried (body mass + 32 kg). V_{O2} was 67 ± 7% (range: 53–79) of the firefighters' $V_{O2\,max}$ and 85 ± 7% (range: 68–95) of V_{O2} corresponding to LT. Peak V_{O2} observed near the end of the tasks in the heat chamber was 80 ± 7% (range: 66–96) of $V_{O2\,max}$ and 102 ± 8% (range: 87–114) of V_{O2} corresponding to OBLA. Thus, on the basis of measured V_{O2}, the firefighters worked at or under intensities corresponding to OBLA and much below intensities corresponding to $V_{O2\,max}$ (Figure 2).

At the end of the Trondheim test, the blood lactate concentration was 9 ± 2 mmol/L, the RPE was 5.8 ± 1.6, and the heat sensation was 2.8 ± 0.6 (*hot* = 3). There were no differences in any of these parameters between faster and slower firefighters; the test was as demanding for the faster and for the slower firefighters.

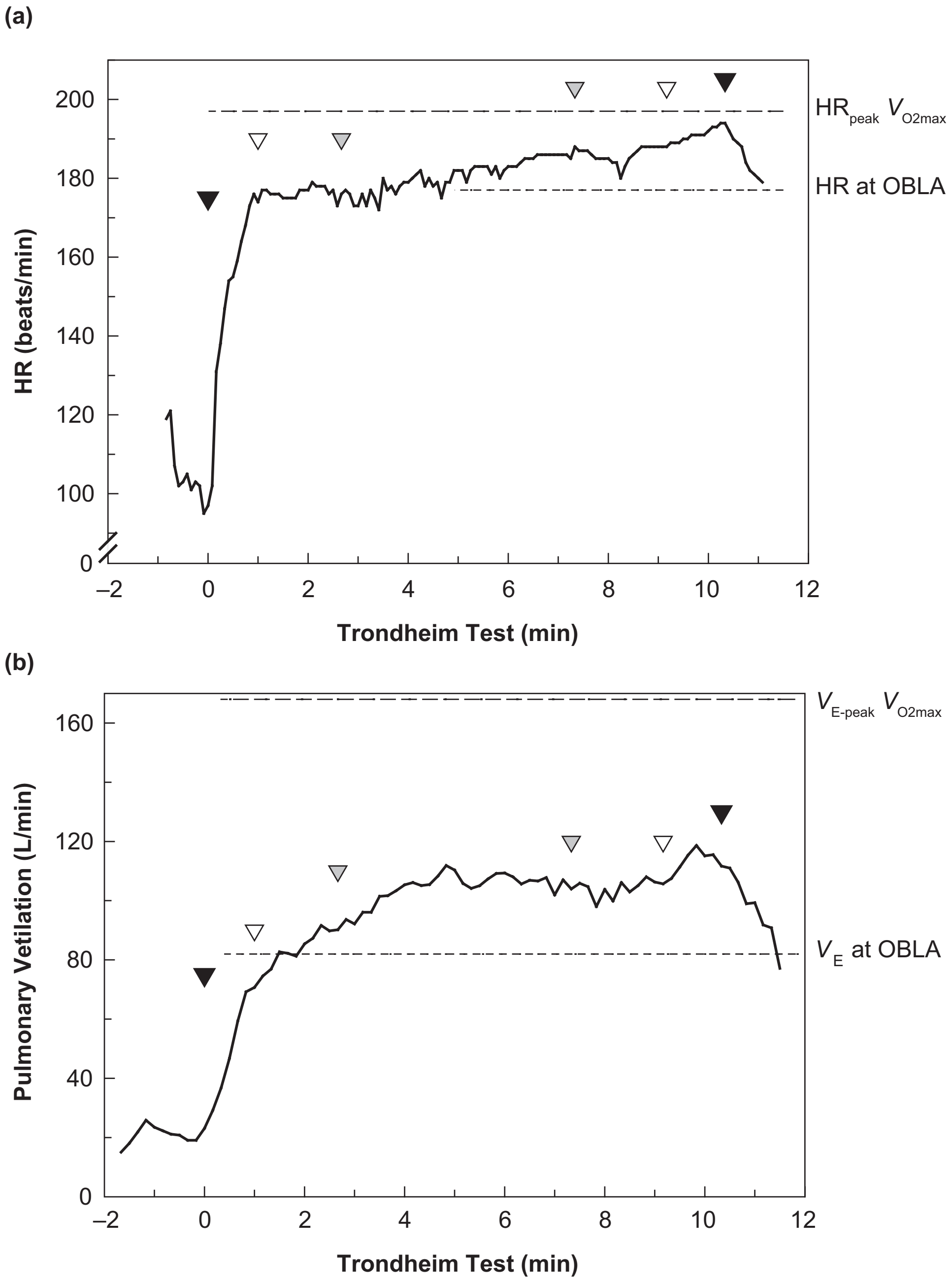

Figure 1. HR and pulmonary ventilation during Trondheim test. *Notes.* (a) HR of a typical firefighter (A) during the Trondheim test, who carried out the physical part of the test in 10 min 20 s; (b) pulmonary ventilation of the same firefighter during the same test. The arrowheads denote (left to right) start of the physical tasks (▼), end of the first hose dragging (▽), start and end of work in the heat chamber (▽), start of the second hose dragging (▽) and end of physically demanding tasks (▼). The dashed lines indicate the corresponding values during $V_{O2\,max}$ test and the OBLA test. HR = heart rate, $V_{O2\,max}$ = maximal oxygen uptake, OBLA = onset of blood lactate accumulation.

3.2.2. Physiological responses versus test duration

The faster firefighters consumed O_2 at a higher rate than the slower ones. However, because of the longer test duration, accumulated V_{O2} (V_{O2} integrated over the test duration) was higher for the slower firefighters (p < .001; Figure 3a). For the same test duration, heavier firefighters consumed more O_2 than lighter ones. The effect of the test duration on accumulated V_{O2} was the same whether the accumulated V_{O2} was expressed in absolute terms, per kilogram of body mass, or

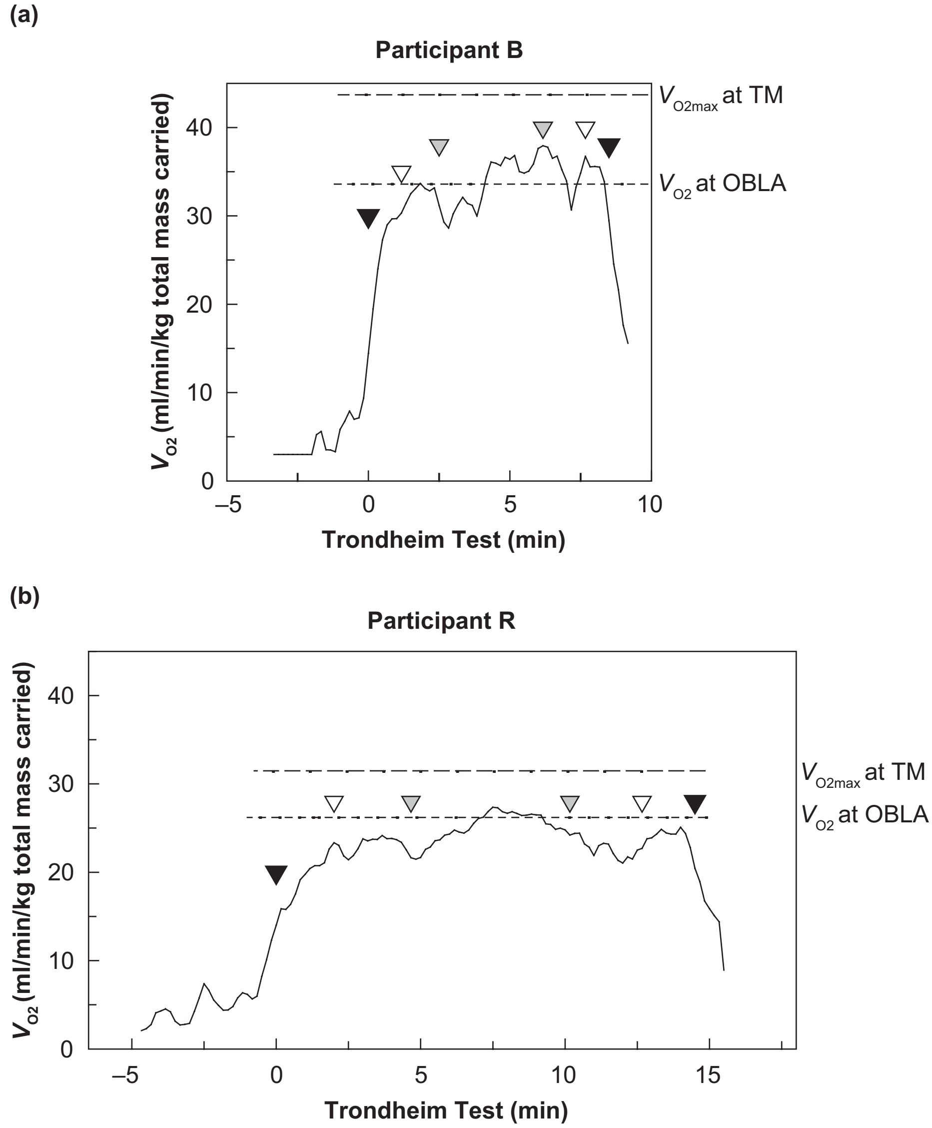

Figure 2. V_{O2} measured during Trondheim test of firefighters. *Notes.* (a) data of B, a quite fit and fast firefighter weighing 88 kg and completing the physical part of the test in 8 min 30 s; (b) data of R, a physically less fit firefighter weighing 86 kg and completing the physical part of the test in 14 min 30 s. Each firefighter's $V_{O2\,max}$ and V_{O2} corresponding to his OBLA are shown with dashed lines. The arrowheads denote (left to right) start of the physical tasks (black ▼), end of the first hose dragging (▽), start and end of work in the heat chamber (▽), start of the second hose dragging (▽) and end of physically demanding tasks (black ▼). The curve of V_{O2} has been corrected for a 30-s delay in V_{O2} as measured with the MetaMax II because of built-in delays and averagings in the instrument's hardware [39]. TM = treadmill, V_{O2} = oxygen uptake, $V_{O2\,max}$ = maximal oxygen uptake, OBLA = onset of blood lactate accumulation.

per kilogram of total mass carried (body mass + 32 kg). However, the values for the female participant were in the lower range when expressed in absolute terms and in the higher range when expressed in relation to the total mass.

The amount of air breathed in during the physical part of the test rose with the test duration ($p < .001$; Figure 3b). Consequently, slower and less fit participants consumed more air than faster and better fit participants; the results were the same when the amount of air consumed was expressed in absolute terms, per kilogram of body mass, or per kilogram of total mass carried. However, the values for the female participant were in the lower range when expressed in absolute terms and in the higher range when expressed in relation to the total mass (Figure 3b).

Each firefighter breathing in from SCBA with maximum allowable pressure of 300 bar. During the test, the pressure fell by 206 ± 31 bar (range: 160–280), which means that the average firefighter used ~70% of the available air supply, and 1 participant used over than 90%.

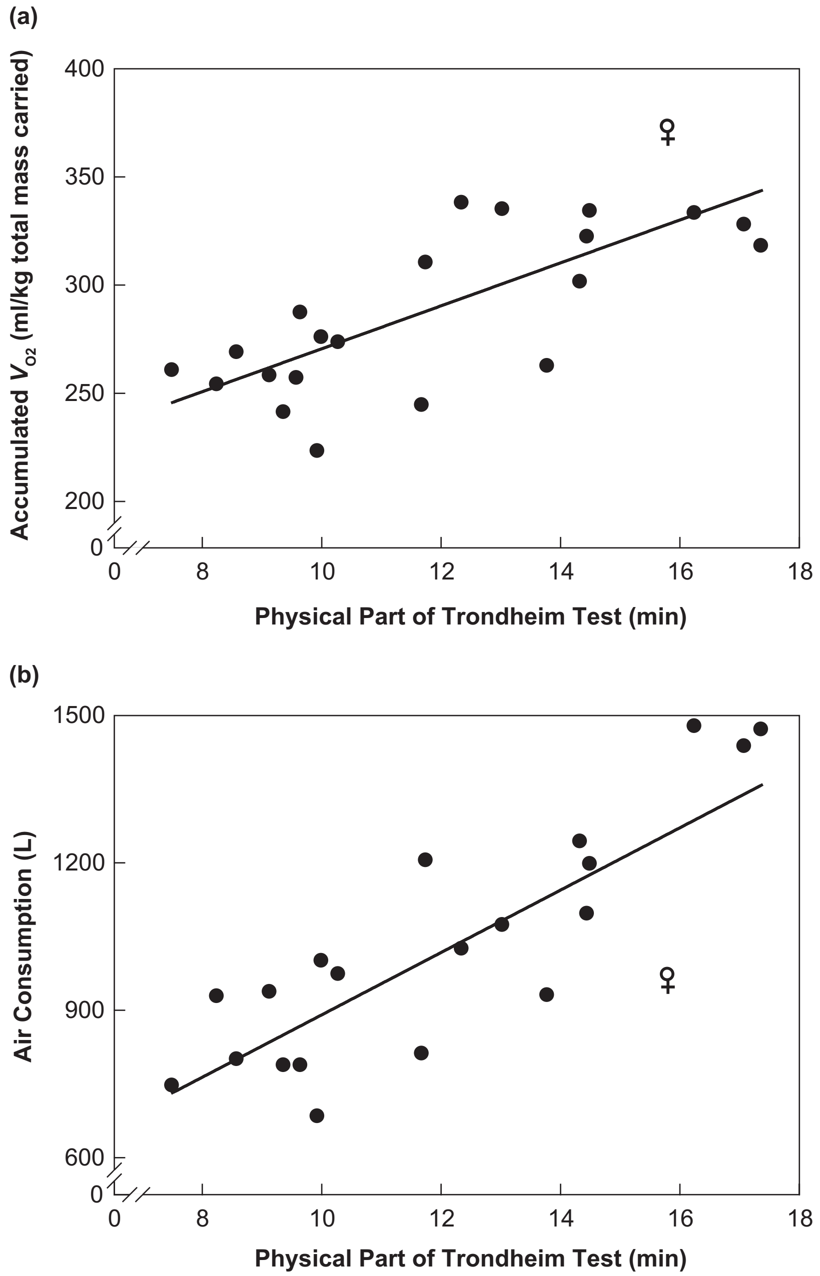

Figure 3. V_{O2} and air breathed during the physical part of Trondheim test versus duration of the physical part (n = 22). *Notes.* (a) accumulated V_{O2}. Pertinent regression parameters are {Y} = 171 + 9.9 {x}; s_b = 1.9 ml/min/kg; $s_{Y|x}$ = 27 ml/kg; r = .75. (b) amount of air breathed. Pertinent regression parameters are {Y} = 256 + 63 {x}; s_b = 10 L/min; $s_{Y|x}$ = 140 L; r = .82. The study involved 22 professional firefighters, 21 male (●) and one female (♀), who carried out the test as fast as possible while V_{O2} was measured continuously; data on the volume of air consumed were not obtained on one male firefighter. Data on V_{O2}, air consumption and time spent on nonphysical tasks of the test at the start and end (dressing and undressing, mounting instruments, solving puzzles) are not included. V_{O2} = oxygen uptake, s_b = error of slope, $s_{Y|x}$ = error of regression, r = correlation coefficient.

3.3. Relations Between Result of Trondheim Test and Laboratory Tests

Firefighters with high $V_{O2\,max}$ completed the test faster than firefighters with lower $V_{O2\,max}$ (Figure 4). Moreover, firefighters with high $V_{O2\,max}$ had higher V_{O2} during the test. Consequently, mean V_{O2} during the test and the test duration were related. The correlation between $V_{O2\,max}$ and V_{O2}

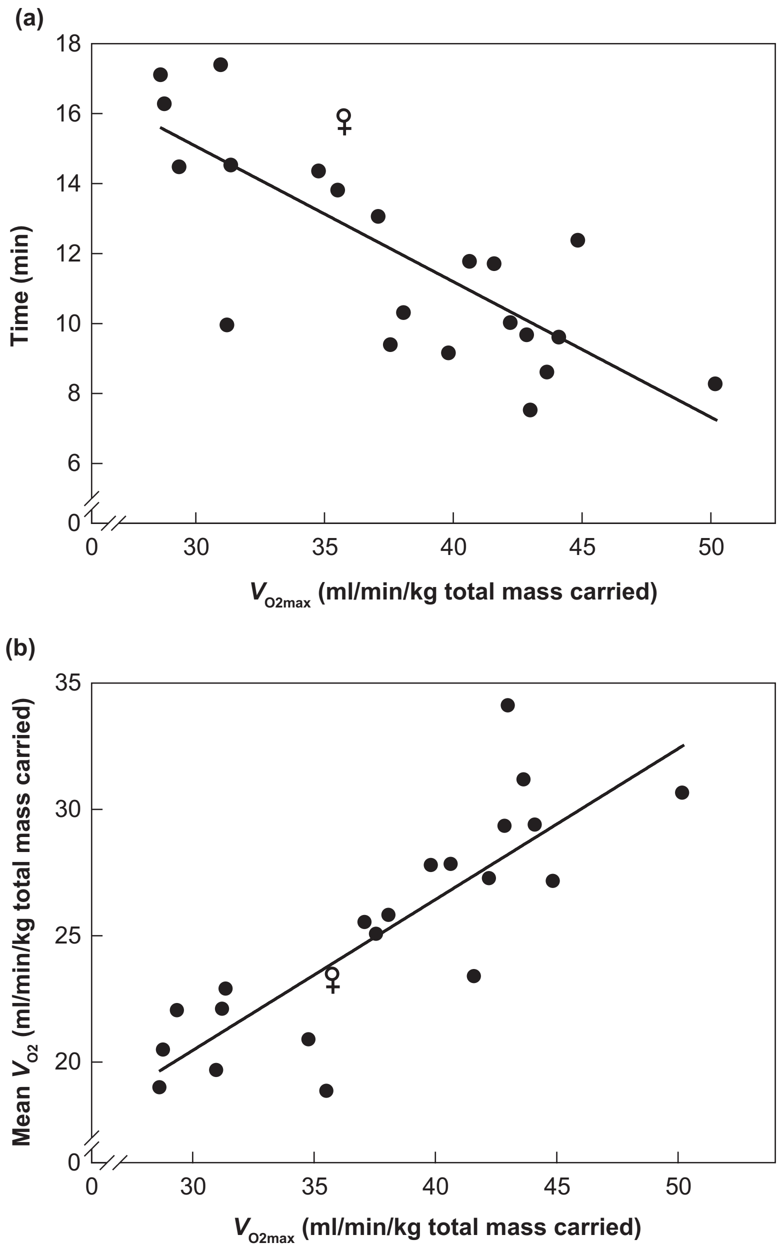

Figure 4. Time and mean V_{O2} during the physical part of Trondheim test versus $V_{O2\,max}$ (n = 22). *Notes.* (a) time of the physical part of the test. Pertinent regression parameters are $\{Y\} = 29 - 0.39\,\{x\}$; s_b = 0.07 ml/min/kg; $s_{Y|x}$ = 2.0 min; r = .77. (b) mean V_{O2}. Pertinent regression parameters are $\{Y\} = 2.6 + 0.60\,\{x\}$; s_b = 0.09; $s_{Y|x}$ = 2.4 ml/min/kg; r = .84. The study involved 22 professional firefighters, 21 male (●) and one female (♀), who carried out the test as fast as possible while V_{O2} was measured continuously. Data on V_{O2} and on time spent on nonphysical tasks of the test at the start and end (dressing and undressing, mounting instruments, solving puzzles) are not included. $V_{O2\,max}$ was measured during walking on the treadmill dressed as a smoke diver and carrying 23 kg of protective clothing and breathing apparatus. V_{O2} = oxygen uptake, $V_{O2\,max}$ = maximal oxygen uptake, s_b = error of slope, $s_{Y|x}$ = error of regression, r = correlation coefficient.

at OBLA of the firefighters was r = .92, which means that both parameters expressed the same capability. Consequently, the patterns in Figure 4 remained almost the same if V_{O2} at OBLA replaced $V_{O2\,max}$.

4. DISCUSSION

V_{O2} was measured continuously during simulated fire fighting tasks, including work in a heat chamber, while the firefighters breathed in from SCBA. The test was physically demanding as judged from the high V_{O2}, HR and pulmonary ventilation during the test, and from high blood lactate concentration and the RPE at the end of the test. Moreover, the Trondheim test clearly distinguished between physically fit and less fit subjects. Faster and fit participants used less air than slower and less fit participants.

4.1. Physical and Physiological Demands of Trondheim Test

The Trondheim test has been designed for Norwegian smoke divers to mimic real fire fighting tasks, including tasks in a heat chamber. The participants breathed in from SCBA, which adds extra resistance to breathing [1, 2] and that may limit the ventilation compared with normal breathing [1], reduce performance [3, 4, 5] and put further demands on the firefighters. Because the test includes tasks like hose connecting and disconnecting, and balancing, which are not very demanding physically and may allow partial recovery during the test, physical demands of the test might be lower than those of other tests. The average V_{O2} of 2.9 L/min during the test is among the highest values reported for firefighters' tests. Moreover, the fastest participants had the highest $V_{O2\,max}$ measured during the treadmill test. Physically fit participants performed skill and agility tasks faster than less fit participants; these tasks also divided the participants according to the fitness level. The Trondheim test is as physically demanding as other tests for firefighters; it distinguishes physically fit and less fit participants; this corresponds with the results of other studies on simulated fire fighting tasks [14, 18, 20]. However, the Trondheim test may be more similar to real fire fighting than former studies because of its various tasks like activities in the heat chamber and because the participants breathe in from SCBA.

The most demanding tasks during the test were tasks in the heat chamber carrying blocks of concrete. According to Smith, Petruzzello, Kramer, et al., a 16-min standardised physical task was much more demanding when performed in the heat than at normal temperatures [15]. Hose dragging was also demanding as judged from V_{O2}, HR and pulmonary ventilation. These results correspond with the results of a Swedish investigation showing that tasks like dragging, pulling, pushing and carrying make a fire fighting job demanding [42].

Physical demand of the test was measured with direct methods like V_{O2} and HR; subjective rating may not reflect physical demand. Bugajska, Zużewicz, Szmauz-Dybko et al. found that HR of firefighters climbing ladders, climbing stairs and carrying firehoses, and rescuing victims rose close to the maximum during each task [28]. However, their firefighters described climbing ladders as easy, climbing stairs and carrying firehoses as a moderate load, but rescuing a victim as strenuous.

4.2. Test Duration, Air Consumption and Pulmonary Ventilation

The Trondheim test lasts at least 15 min for most participants (including tasks not being physically demanding). This duration corresponds to the time of a common effort during fire fighting. Consequently, the average participant used ~70% of the air supply during one test, and a few slow participants used ~90% of their supply. A drawback of the test is the time needed to test many firefighters.

Because a smoke diver breathes in from SCBA carried on the back, the amount of available air is limited. Despite higher ventilation rate of faster and physically fit participants, slower participants used more air. Thus, the lower air consumption needed to perform a specific set of tasks is another advantage of being physically fit. Former studies described problems and limitations of air reserve during smoke diving [14, 19, 22, 23, 24]. Several studies showed that a firefighter may run out of air within ~20 min during strenuous exercise. Data in the present study support the findings of former studies and show that physically fit firefighters may use their limited air supply more economically.

4.3. $V_{O2\,max}$

The participants' $V_{O2\,max}$ was recorded during treadmill walking, rather than during standard running on the treadmill; the participants were dressed as firefighters. This difference may be important since in a previous study there was no clear relationship between $V_{O2\,max}$ during treadmill running and performance time during rescue work at a hospital [17]. In the present study, where the participants wore firefighter's equipment and carried heavy loads during the $V_{O2\,max}$ test, there was a close relationship between performance time and $V_{O2\,max}$ and LT. This suggests that $V_{O2\,max}$ depends on the test and that the effect of a test type may differ between participants.

During real smoke diving, the firefighter breathes in from SCBA. The breathing apparatus restricts high ventilations and reduces $V_{O2\,max}$ [3]. This aspect of fire fighting is not included in the $V_{O2\,max}$ test used in the present study.

A number of studies suggested that a firefighter should have $V_{O2\,max}$ of at least 40 ml/min/kg [6, 8, 12, 14, 16, 18, 25, 26, 27, 43, 44]. Data in this study agree with the conclusion of former studies.

4.4. Exercise Intensity Relative to LT

Data on V_{O2} during the Trondheim test suggest that the participants exercised at intensities, around or under those corresponding to their LT test. However, HR and ventilation were higher than values corresponding with LT, and the blood lactate concentration at the end of the test was high. These observations may be conflicting about whether the true intensity was under, at or higher than the task-specific LT. No warming-up on the test that involved strenuous hose dragging at the beginning, may be a complicating fact, or this may have increased the blood lactate concentration, HR and ventilation. For example, cross-country skiers' blood lactate concentration was ~10 mmol/L during simulated competitions lasting at least 20 min despite V_{O2} not exceeding the level corresponding with LT [45]. Further studies are needed to find the intensity relative to the true lactate threshold of fire-fighting, and also to examine to what extent thresholds established during laboratory experiments can be extrapolated to field conditions. $V_{O2\,max}$ during real fire fighting tasks could be lower than that measured in the laboratory, even when the participants were dressed as smoke divers as in the present study.

4.5. Work-Simulated Tests or Laboratory Tests?

The small error of regression and high correlation when comparing performance on the Trondheim test with $V_{O2\,max}$ and LT, show that the Trondheim test distinguishes physically fit and less fit participants. This suggests that there were minimal differences in working techniques and tactics between the participants. This study involved only professional firefighters with several years of experience. The results of this study suggest that the Trondheim test could be used to examine adequate physical fitness of professional firefighters. A parallel study has shown that physically fit recruits perform as well as experienced fire fighters on this test [46]. That is a further advantage of this work-simulating test.

Several former studies examined properties and physical demands of applied worksite-type tests for firefighters. A Finnish group performed a test with five specific tasks with a set pace of 14.5 min [14]. The test's O_2 demand was 26 ml/min/kg or 2.1 L/min, which is considerably lower than for the Trondheim test. For participants with $V_{O2\,max}$ above 40 ml/min/kg measured during cycling, the test was easy. For those with $V_{O2\,max}$ under 36 ml/min/kg the test was very demanding. A drawback of the Trondheim test and to some extent of the Finnish test is that the tests are quite site specific and may not be easily performed at all fire stations.

A number of studies, mostly by Canadians, examined tests that can be performed at most fire stations, independently of their specific design [18, 21, 25, 31]. The tests included 8–10 tasks, each solved in less than 1 min. In the Finnish test and in the Trondheim test physically demanding tasks lasted more than 1 min; the latter may be more realistic for real fire fighting. By comparing performance on the Trondheim test with that on a standardised laboratory test, the present study extends results of former studies. Close linear relationships were found. The results suggest that applied tests can be standardised and performed in most fire stations like the tests examined by Canadian groups [18, 21, 25, 31]. Moreover, performance of properly designed tests depends heavily on the firefighters' fitness. Consequently, applied tests may be appropriate for testing firefighters, including setting minimum requirements.

4.6. Methodological Considerations

V_{O2} was measured with the MetaMax II portable analyser. Although the instrument measures V_{O2} breath by breath and reports the results in 10-s intervals, there are built-in averages and delays that reduce the time resolution and delays the output by at least 30 s [39]. Therefore, changes in V_{O2} lasting less than 30 s may not be recorded, while fluctuations lasting 1 min or more are reliable. Exercises in the heat lasted several minutes, and limitations of the instrument have minimal influence on the results. Several other tasks lasted less than 1 min, and conclusions on the O_2 demand of these tasks cannot be drawn, in particular since presumably physically demanding tasks and tasks requiring skill and agility alternated. However, it is important that V_{O2} reached a peak after each hose dragging task which is physically demanding [42].

Another limitation of the MetaMax II is that the measurements of the respiratory exchange ratio are not reliable, like in most portable analysers [38]. Williams-Bell, Villar, Sharrat et al's. data on excess CO_2 release are an indication of anaerobic energy release in their studies [24, 25]. The blood lactate concentration measured in the present study was quite high and supported high physical demands of the Trondheim test.

Because the MetaMax instruments calculate V_{O2} and related quantities from measurements on expired air only, they require an inspiration signal between two expirations [35]. In the present field study only expired air could be lead through the breathing valve. Therefore, the instrument had to be modified and an artificial inspiration signal after each expiration was added. Separate measurements showed that the modified instrument worked properly also when being connected to the outlet of a firefighter's breathing mask [35].

4.7. Conclusion

The Trondheim test, which includes physical work in the heat, is physically demanding. The test discriminated well between aerobically fit and less fit subjects, at least when the $V_{O2\,max}$ was measured when being dressed as a smoke diver. Moreover, faster and physically fit participants used less air than slower and less fit participants, which may be an advantage of being physically fit.

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