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Performance on a Work-Simulating Firefighter Test Versus Approved Laboratory Tests for Firefighters and Applicants

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Aim. *Firefighters must meet minimum physical demands. The Norwegian Labour Inspection Authority (NLIA) has approved a standardised treadmill walking test and 3 simple strength tests for smoke divers. The results of the Trondheim test were compared with those of the NLIA tests taking into account possible effects of age, experience level and gender.* ***Methods.*** *Four groups of participants took part in the tests: 19 young experienced firefighters, 24 senior male firefighters and inexperienced applicants, 12 male and 8 female.* ***Results.*** *Oxygen uptake (V_{O2}) at exhaustion rose linearly by the duration of the treadmill test. Time spent on the Trondheim test was closely related to performance time and peak V_{O2} on the treadmill test. Senior experienced firefighters did not perform better than equally fit young applicants. However, female applicants performed poorer on the Trondheim test than on the treadmill test. Performance on the Trondheim test was not closely related to muscle strength beyond a minimum.* ***Conclusion.*** *Firefighters completing the Trondheim test in under 19 min fit the requirements of the NLIA treadmill test. The Trondheim test can be used as an alternative to the NLIA tests for testing aerobic fitness but not for muscular strength. Women's result of the Trondheim test were poorer than the results of the NLIA treadmill test, probably because of their lower body mass.*

endurance fire fighting gender blood lactate concentration V_{O2} strength tests

1. INTRODUCTION

At the scene of fire, firefighters must move around, lift, pull, drag and carry heavy objects, and they must wear heavy protective clothing. Sometimes they must also be able to assist or to carry victims unable to rescue themselves. Very often firefighters work at high temperatures, which increase physiologic demands. Fire fighting, smoke diving and rescuing are presumably physically demanding, as reflected in high oxygen uptake (V_{O2}) [1, 2, 3, 4, 5, 6, 7] and near-maximum heart rate (HR) [8, 9, 10] during common fire fighting tasks. Firefighters' maximal oxygen uptake ($V_{O2\,max}$) should be ~40 ml/min/kg or more [1, 2, 3, 5, 7, 11, 12, 13, 14, 15, 16, 17]. Laboratory tests [18] and work-simulated tests [15, 19, 20] have been developed to ensure sufficient physical abilities. Tests differ between countries and even between fire departments in

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the same country. A proper test should distinguish those who can and those who cannot do the job, without regard to age, gender or experience; this is a basic idea for the present study.

Because fire fighting includes different physically strenuous tasks, physical fitness tests must examine different physical abilities, not only aerobic power [21, 22, 23, 24]. A test should distinguish aerobic fitness level and muscular fitness. Many studies suggest that a smoke diver should have $V_{O2\,max}$ of at least 40–45 ml/min/kg [1, 2, 3, 5, 7, 11, 12, 13, 14, 15, 16, 17], but there are no necessary data about minimum requirements for muscular strength and fitness.

To establish minimal acceptable scores for a work-simulated test (cut-off scores), the test should be compared with standards. The Norwegian Labour Inspection Authority (NLIA) has established a set of minimum requirements based on simple laboratory tests. The main part of those requirements is an aerobic fitness test where each participant, dressed as a smoke diver, walks for 8 min on the treadmill on preset conditions. To pass the test, participants have to complete the 8-min standardised treadmill walk. Those who abort the test before completing 8-min walk, fail. According to the NLIA, other tests with similar physical requirements may be used as substitutes for the approved test. The Trondheim fire brigade (Norway) has developed a work-simulating test to evaluate job-related physical abilities for firefighters and applicants based on the time to conclusion. That test includes a number of fire fighting tasks, but there are no data on the extent to which the Trondheim test distinguishes physically fit and less fit participants and on the proper cut-off value. The NLIA has also established minimum requirements for muscular strength. The Trondheim test includes tasks like lifting heavy objects, carrying and dragging and may distinguish stronger and weaker participants. It is, thus, not known whether muscularly weak participants may pass the Trondheim test.

The main aim of this study was to examine relationships between performance on the work-related Trondheim test, and aerobic and muscular fitness measured with the NLIA approved tests. Attempts to establish a cut-off score of the Trondheim test were made. The study also examined to what extent different parts of the test distinguished participants.

Since the Trondheim test mainly consists of physically demanding tasks, it was hypothesised that there was a close linear relationship between the results of the NLIA approved treadmill test and the Trondheim test. It was also hypothesised that performance on the Trondheim test distinguished muscularly strong and weak participants measured with the NLIA strength tests. Moreover, it was hypothesised that for the same physical ability (aerobic power, muscular strength), performance on the Trondheim tests did not depend on age, gender, experience level or body mass.

2. METHODS

2.1. Experimental Approach to Problem

The NLIA treadmill test is a simple pass or fail test (dichotomous outcome). To obtain continuous interval values, the test was modified. The exercise was extended with stepwise increases in the intensity to volitional exhaustion; time to exhaustion and peak V_{O2} were obtained as continuous outcome variables of aerobic fitness. To test the last prediction (independence of age, gender and experience level), the participants were divided into four categories: 19 young (under 40 years) and 24 senior (over 40 years) experienced male firefighters and inexperienced young applicants of both genders (12 men and 8 women). Individual data were also examined to see whether body mass mattered. Five female applicants passed all the NLIA tests, while the 3 other failed on several tests. Data of the 5 successful applicants were treated separately to allow comparison with the men.

Employed firefighters complete physical tests every year to monitor their physical fitness. Applicants are also tested as part of the intake examination for possible firefighters' candidates. The two test regimes compared in this study, the Trondheim test and the NLIA tests, were used as part of the firefighters' and the applicants' fitness examinations at the Trondheim fire brigade in Norway. No females were employed at the time of this study.

Performance on the Trondheim test (dependent variable) was the time needed to complete the whole test. To set a cut-off on the Trondheim test equivalent to that of the NLIA approved test, the 8-min cut-off set on the NLIA treadmill test was used in a regression model.

The Trondheim test consists mostly of physically strenuous exercise tasks, but it also includes tasks that require skill and agility. Time spent on each task was calculated separately to examine whether age, experience, gender and physical fitness may influence skill and agility performance and performance on physically strenuous tasks.

2.2. Participants

The firefighters had been employed for over 3 years; they had completed the Trondheim test 8 ± 3 times ($M \pm SD$). The inexperienced applicants (all under 40 years) had minimal experience with fire fighting tasks, including the Trondheim test (≤1 time). The characteristics of the 5 female applicants who passed all the formal NLIA tests, did not differ much from the characteristics of the whole group of female applicants, apart from a lower proportion of body fat (M = 22%); further details are therefore not given. Table 1 shows characteristics of the four groups of participants in this study.

Before the tests, the participants were examined and informed orally and in writing about the experiments before they gave their written consent. The participants knew that they were volunteers in the scientific part of the examinations and could leave the study at any stage without giving a reason. The participants were also assured that withdrawal from the study would not affect their future work as smoke divers. The Regional Committee for Medical Research Ethics of Central Norway approved the study.

2.3. Procedures

The participants performed the extended NLIA treadmill test, the NLIA strength tests and the Trondheim test in random order within a one-week period (in September or October) separated by at least one day. According to the instructions, the participants did not eat less than 2 h before the tests and they did not smoke or consume alcohol the day before the tests. The applicants, unfamiliar with the test protocols, were instructed and guided before the tests. During the tests, each participant was verbally encouraged to ensure optimal performance.

2.4. Dressing Procedure

During the NLIA tests, the firefighters were dressed as smoke divers, and they had the standard protective equipment including a fireproof jacket and pants, and isolating underwear. However, a helmet and a breathing mask were not used to allow V_{O2} measurements. Moreover, jogging shoes replaced the standard protective boots to avoid overloading the Achilles tendon. The

TABLE 1. Characteristics of Participants

	Experienced Firefighters		Inexperienced Applicants	
Parameter	Senior (n = 24)	Young (n = 19)	Male (n = 12)	Female (n = 8)
Age (years)	48 ± 5***	33 ± 3	30 ± 7	27 ± 4
Body mass (kg)	84 ± 9	84 ± 11	83 ± 9	66 ± 8♀♀♀
Height (m)	1.81 ± 0.06	1.82 ± 0.07	1.83 ± 0.05	1.67 ± 0.04♀♀♀
BMI (kg/m^2)	25.8 ± 2.5	25.2 ± 2.7	24.8 ± 2.7	23.6 ± 2.4
Waist/hip circumference ratio	0.94 ± 0.05**	0.90 ± 0.04	0.89 ± 0.04	0.87 ± 0.05
Body fat (% of body mass)	24.0 ± 6.8**	18.5 ± 4.1	15.4 ± 5.6	25.5 ± 6.7♀♀
Lean body mass (kg)	64 ± 5**	68 ± 7	70 ± 5	49 ± 3♀♀♀

Notes. *p < .05, **p < .01, ***p < .001 for senior firefighters versus young men; ♀♀p < .01, ♀♀♀p < .001 for female applicants versus young men. The data are $M \pm SD$ of the number of participants. There were no differences between young firefighters and young male applicants. Senior firefighters = firefighters ≥40 years old; young firefighters and applicants = firefighters and applicants <40 years; BMI = body mass index; body fat = body fat calculated from 4 skin fold measures; lean body mass = body mass less calculated fat mass.

participants also had a backpack harness with a self-contained breathing apparatus (SCBA), but they breathed in indoor air (20–24 °C). The whole outfit weighed 23 kg. However, for the horizontal chest-to-bar pull-up test, described in the following subsection, the firefighters wore only fire-protective clothing (~5.5 kg), without SCBA. During the Trondheim test, simulating real fire fighting, the firefighters wore the whole protective outfit, including SCBA and boots (28–29 kg of extra mass).

2.5. NLIA Tests

2.5.1. Extended NLIA treadmill test

The first 8 min of the test was the standard NLIA test. 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 at that level for the next 6 min. This test has an O_2 demand of ~32 ml O_2/min/kg total mass carried (~41 ml/min/kg body mass). On the extended version of the test, the treadmill inclination was raised to 14% and kept at that level for the rest of the test. If the participant was able to continue the exercise beyond 9 min of walking, the speed was increased by 0.056 m/s (0.2 km/h) every minute until exhaustion.

HR (heart rate monitor Polar Accurex Plus PE 3000; Polar Electro, Finland) and V_{O2} (portable metabolic analyser MetaMax II; Cortex Biophysik, Germany) were measured continuously during the test. 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 rating of perceived exertion (RPE) was recorded with the Borg CR10 scale at exhaustion [25]. The blood lactate concentration was measured after 8 min and at exhaustion with a portable LT-1710 Lactate Pro analyser (Arkray, Japan). These instruments provided valid and reliable values [25, 26, 27, 28].

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

2.5.2. NLIA strength test

The NLIA has established three simple strength tests. The established norms were based on the experience and trial and error briefly summarized in Scandinavian reports. Thus, these tests do not have a formal physiological basis like the treadmill test described in section 2.5.1.

Push-ups

The participant, dressed as a smoke diver (bearing 23 kg), did as many push-ups as possible. The number of push-ups was recorded. According to the directions, the test ended when the participant was no longer able to keep the body straight. The NLIA's minimum requirement is seven push-ups.

Squat-and-raise

During the squat-and-raise test, the participant, dressed as a smoke diver (bearing 23 kg), stood close to a wall bar with both hands on the bar at the height of the iliac crest during normal standing. A point 10 cm above the top of the head (called +10 cm mark) was marked. The body was first lowered so the thighs were horizontal, then the body was raised so that the head reached the +10 cm mark. The number of completed squat-and-raise was recorded. Most participants reached the +10 cm mark by standing on their toes. Both arms were kept straight during the test. The task was repeated without rest or break until the participant was unable to reach the +10 cm mark or to work continuously. The NLIA's minimum requirement is 15 repetitions.

Horizontal chest-to-bar pull-ups

The participant, wearing fire-protecting clothing without SCBA (~5.5 kg), lay horizontally (supine) with the heels on a low chair or bench. A beam (14 cm high) was positioned so that when the participant gripped the beam (supinated grip) and hung down with straight arms, the shoulder

joints were at the same level as the heels. Then the participant pulled up until the chest touched the bar. The number of repetitions was recorded. The body had to be kept straight and static during the exercise. The task was repeated until the participant was unable to raise the chest to the bar. The NLIA's minimum requirement is seven chest-to-bar pull-ups. Because the body was horizontal and the heels were supported, the force on the arms was considerably lower than the body weight, especially for a woman with a slender upper body.

2.6. Trondheim Test

The Trondheim test consisted of three main parts: (a) "emergency" where the firefighter did seven essential tasks to reach "the scene of fire", (b) physical work at the scene of fire and (c) "retreat" from the scene of fire. Before the start, SCBA was checked and the air pressure was recorded. After the start, the participant walked 5 m to the first task:

- Part 1: "emergency"
  - *Puzzle (mental challenge).* The participant had to solve a small puzzle of 20 pieces (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 falling down, the participant 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 participant 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, equipped with a flashlight, did physical work in the heat chamber kept at 120–140 °C with 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. One block was moved at a time. 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 time necessary to complete the test and individual tasks was recorded.

The total distance walked during the whole test was 582 m. The test should be completed as quickly as possible. The blood lactate concentration and the RPE were recorded immediately after the test. The SCBA pressure was read again. Each participant's volume of breathed air was the pressure difference multiplied by the volume of the bottles. HR was recorded throughout the test, and the relative intensity was taken from peak HR and average HR during the test.

Hose dragging, carrying heavy cans, walking 58 m, and tasks in the heat chamber were classified as physically strenuous. Balance, hose connection and disconnection, tunnel crawling were

classified as skill and agility tasks. Puzzle solving was treated separately. The test–retest variability of 36 firefighters doing this test at least one year apart, averaged 50 seconds (5%) including large deviations that may reflect changed performance level.

2.7. Anthropometric Measurements

Body mass was measured with a digital scale (Heine, Germany); its error of measurement was ± 0.2 kg. Waist and hip circumference were measured with a flexible tape and used to compute the waist-to-hip ratio according to standardised procedures [29]. Skinfolds were measured with a Harpenden skinfold calliper (John Bull, British Indicators, UK) at four different places: m. biceps brachii and m. triceps brachii, subscapular skin fold and supra-iliac skin fold. The proportion of body fat was calculated using the sum of these four skinfold measurements in line with common directions [30].

2.8. Data Handling

The highest V_{O2} and peak HR at the tests were taken as the median of the three successive highest recordings. To calculate a strength index for each participant, the mean ($\bar{x}$) and standard deviation (s) of all data for all groups were calculated for each test; for each participant's performance (x_i) a z-score was taken as $z_i = (x_i - \bar{x})\ s^{-1}$. The participant's strength index was taken as the mean of the z-score for each test. There were missing data of 5 participants on the three strength tests.

2.9. Statistics

The data were summarized as mean (M) ± standard deviation (s) for the number of the participants. The data were analysed with a one-way analysis of variance (ANOVA) using the four different groups as categories. It appeard that many parameters of the young firefighters and the male applicants (called young men) were similar and did not differ significantly. Their results of individual parameters were gathered for further comparisons to obtain higher statistical power. Data of the senior firefighters and the female applicants have been compared with the young men's results using Fisher's least significant difference (LSD) for post-hoc analysis. SPSS version 15.0.1 was used for data analysis; type IV of sums of squares was used because the data were unbalanced.

Linear regressions and regression parameters were calculated in a dedicated spreadsheet; the error of regression (scatter around the regression line, $s_{Y|x}$) was the principal measure of aerobic fitness. When two parameters were linearly related, possible differences between the four groups' regression lines were examined with analysis of covariance when the slopes for the different groups were similar.

3. RESULTS

3.1. Extended NLIA Treadmill Test

3.1.1. Peak V_{O2}

Peak V_{O2} measured during the extended treadmill test rose linearly by the duration and the intensity of exercise; the average increase was 0.12 L/min or 1.4 ml/min/kg total mass carried for a 1 min increase in duration (Figure 1). These results corresponded to an average walking cost of 0.43 ml O_2/m/kg (19 µmol O_2/m/kg) at 14% inclination. The relationship between the three groups of men did not differ, but for the women peak V_{O2} was 0.8 L/min lower than for the men for the same exercise duration ($p < .001$; Figure 1a). The women weighed less than the men, and the relationship between the men and the women did not differ when expressing V_{O2} relative to the total mass carried (Figure 1b). The regression analysis showed that the time to exhaustion accounted for 77% of the variance ($r = .88$) in the dependent variable peak V_{O2} for these participants ($p < .001$). Peak V_{O2} could be estimated from the time to exhaustion with an error of 3 ml/min/kg total mass carried. These findings showed that the participant's peak V_{O2} measured at the end of the extended exercise could be predicted satisfactorily and quite precisely from the duration of the extended treadmill test.

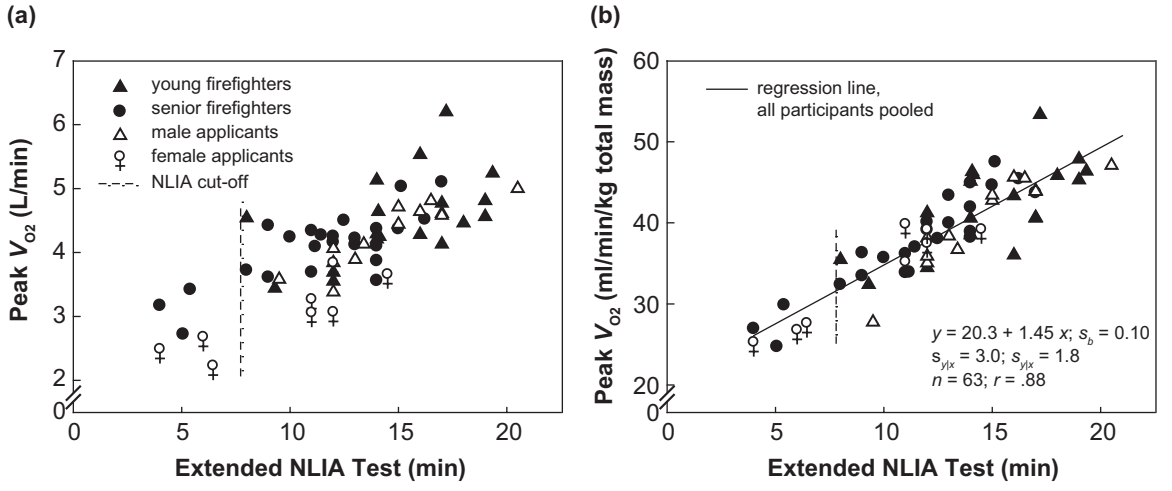

Figure 1. Peak V_{O2} versus time to exhaustion on extended NLIA test. *Notes.* (a) peak V_{O2} in absolute values; (b) peak V_{O2} related to the total mass carried (body mass + 23 kg of the equipment). Dashed vertical lines indicate the lowest accepted performance time (NLIA's cut-off). n = number of subjects, s_b = error of the slope, $s_{Y|x}$, $s_{X|y}$ = errors of regression, r = correlation coefficient, NLIA = Norwegian Labour Inspection Authority.

Peak V_{O2} was lower for the senior firefighters and for the female applicants. The senior firefighters did not differ from the other groups in any physiological parameter at exhaustion, apart from the lower HR (Table 2).

3.1.2. Time to exhaustion

Altogether 57 participants, including all young men, completed the 8-min NLIA treadmill test; V_{O2} of 31.6 ± 2.0 ml/min/kg total mass carried after 8 min of exercise did not differ between the groups. Only 55 of these participants continued the exercise at increasing intensity for another 1–12.5 min to volitional exhaustion. The exercise time differed systematically between the groups ($p < .001$). There were no differences between the young firefighters and the male applicants who exercised for a longer time than the other two groups. The female applicants stopped before the male groups (Table 2).

TABLE 2. Results of Extended Norwegian Labour Inspection Authority (NLIA) Treadmill Test

	Experienced Firefighters		Inexperienced Applicants		
Parameter	Senior (n = 24)	Young (n = 19)	Male (n = 12)	Female (n = 8)	Female[a] (n = 5)
Time to exhaustion (min)	11.5 ± 3.4**	15.1 ± 3.2	14.3 ± 3.0	9.6 ± 3.7♀♀	12.1 ± 1.4
Peak V_{O2} (L/min)	4.08 ± 0.54*	4.54 ± 0.67	4.26 ± 0.52	2.99 ± 0.56♀♀♀	3.33 ± 0.35♀♀
Peak V_{O2} (ml/min/kg total mass carried)	37.8 ± 5.8*	42.3 ± 5.3	40.0 ± 5.7	33.4 ± 6.2♀♀	37.8 ± 1.9
Peak V_{O2} (ml/min/kg body mass)	48.7 ± 8.3*	54.6 ± 7.2	51.8 ± 7.8	45.9 ± 8.9♀	52.1 ± 2.8
Peak HR (beats/min)	175 ± 9***	188 ± 11	192 ± 17	186 ± 8	181 ± 6♀
cLa$_B$ at exhaustion (mmol/L)	10.2 ± 1.7	11.4 ± 2.0	10.0 ± 1.9	11.2 ± 2.0	11.0 ± 1.3
CR-10 at exhaustion	8.3 ± 1.8*	9.1 ± 1.2	9.3 ± 0.7	9.6 ± 1.1	9.4 ± 1.3

Notes. *$p < .05$, **$p < .01$, ***$p < .001$ for senior firefighters versus young men, ♀$p < .05$, ♀♀$p < .01$, ♀♀♀$p < .001$ for female applicants versus young men. The data are $M \pm SD$ of the number of the participants. There were no statistically significant differences between the male applicants and the young firefighters; therefore, their data were pooled (called young men) for post-hoc analysis. a = 5 female applicants who complete the standard 8-min NLIA treadmill test, V_{O2} = oxygen uptake, total mass carried = body mass + 23 kg (protective clothing and self-contained breathing apparatus), HR = heart rate, cLa$_B$ = blood lactate concentration, CR-10 = rating of perceived exertion measured with the Borg CR10 scale.

3.2. Performance on Strength Tests

The strength scores of the squat-and-raise, and push-up tests differed systematically between the groups ($p < .02$). The results of the chest-to-bar pull-up test of the 8 women were lower than the results of the young men (Table 3), but their performance did not differ significantly from that of the senior firefighters. The pooled strength index differed between the groups ($p = .001$). The strength index of the 5 female applicants who completed the 8-min NLIA test averaged –0.37, which is similar to that of the senior firefighters (Table 3).

3.3. Performance on Trondheim Test

The time needed to complete the test and its individual parts differed systematically between the groups ($p < .01$). One female applicant was unable to complete the Trondheim test, and she also failed on the NLIA approved treadmill test and the push-up test; no further data on her performance are given.

The young firefighters completed the test faster than the senior firefighters (Table 4). The time needed to complete different parts did not differ significantly between the young firefighters and the male applicants. The senior firefighters and the 7 female applicants needed ~20% and 80%, more time respectively to complete physically strenuous tasks than the young men. The young men performed the skill and agility tasks faster than the senior firefighters and the female applicants. A further examination showed that there was a close linear relationship between the time spent on skill and agility tasks and on the whole test; the skill and agility tasks took only 17%–18% of the total time (Figure 2). The young firefighters solved the puzzle faster than the senior firefighters (Table 4). Part 1 and 3 of the test included the same tasks. The firefighters completed part 3 faster than part 1 ($p = .002$). For the applicants there were large variations, but on average they spent at least as much time on part 3 as on part 1 ($p = .08$; Table 4).

The participants finishing the test in under 19 min, spent in average ~37% of their total time in the heat chamber. Participants performing the test in over 19 min spent relatively more time in the heat chamber (Figure 2b). There was thus a breakpoint in the relationship between the time needed for part 2 and the total time. Moreover, 2 of the 3 females who completed the whole test in under 19 min, spent relatively more time in the heat chamber than the male participants who completed the test as fast as these women.

Peak HR was reached at the end of the tasks in the heat chamber and was similar to that at the end of the extended treadmill test. The mean HR during the test was 90% of the peak HR for all participants. The blood lactate concentration at the end of the test was 9 mmol/L (Table 4). Nevertheless, the applicants rated the test as being more demanding than the firefighters ($p < .001$). Each participant used ~1.5 m^3 of air during the test, and there were no systematic differences between the groups of participants. However, the amount of air breathed in rose by the duration of the exercise ($r = .52$; $p < .001$).

TABLE 3. Results of Extended Norwegian Labour Inspection Authority (NLIA) Strength Tests

	Experienced Firefighters		Inexperienced Applicants		
Parameter	Senior ($n = 19/21$[b])	Young ($n = 17$)	Male ($n = 12$)	Female ($n = 8$)	Female[a] ($n = 5$)
Push-ups (repetitions)	12 ± 6**	16 ± 6	17 ± 4	6 ± 4♀♀♀	9 ± 1♀♀
Squat-and-raise (repetitions)	27 ± 13**	41 ± 22	37 ± 9	21 ± 6♀♀	23 ± 4♀
Horizontal chest-to-bar pull-ups (repetitions)	14 ± 6	15 ± 5	18 ± 4	12 ± 8♀	15 ± 8
Strength index (mean *z*-score)	–0.23 ± 0.74**	0.33 ± 0.72	0.45 ± 0.48	–0.76 ± 0.75♀♀♀	–0.37 ± 0.59♀

Notes. **$p < .01$, ***$p < .001$ for the senior firefighters versus young men; ♀$p < .05$, ♀♀$p < .01$, ♀♀♀$p < .001$ for the female applicants versus young men. The data are $M \pm SD$ of the number of participants. There was no statistically significant difference between the male applicants and the young firefighters for any parameter, therefore, their data were pooled for the post-hoc analysis. a = 5 female applicant who fulfilled all formal requirements, strength index = mean of *z*-scores of the three strength tests, b = 19 for senior firefighters on the push-up test.

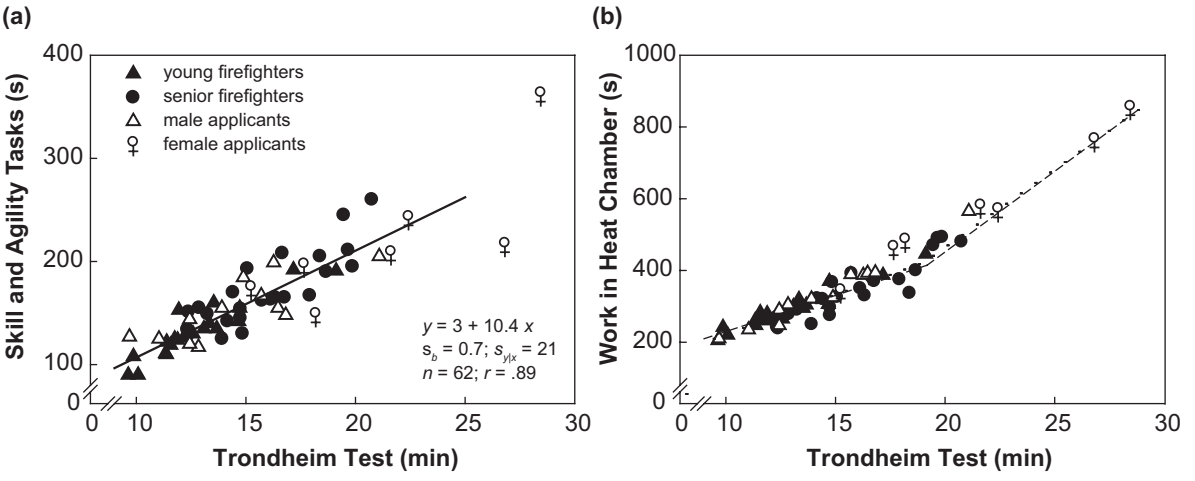

Figure 2. Time spent on skill and agility tasks, and in heat chamber versus time spent on the whole Trondheim test. *Notes.* (a) time spent on skill and agility tasks versus time spent on the whole Trondheim test; (b) time spent in the heat chamber versus time spent on the whole Trondheim test. The dashed line was drawn by hand and has a break at 19 min. $s_{Y|x}$ = error of regression, s_b = error of the slope, r = correlation coefficient.

TABLE 4. Results of Trondheim Test

	Experienced Firefighters		Inexperienced Applicants		
Parameter	Senior (n = 24)	Young (n = 19)	Male (n = 12)	Female (n = 7[b])	Female[a] (n = 5)
Total time (s)	951 ± 157**	766 ± 144	868 ± 185	1289 ± 292♀♀♀	1141 ± 178♀♀
Time on part 1 (s)	313 ± 54***	248 ± 43	262 ± 48	346 ± 58♀♀♀	340 ± 65♀♀
Time on part 2 (s)	348 ± 78*	290 ± 59	338 ± 96	576 ± 177♀♀♀	484 ± 95♀♀
Time on part 3 (s)	291 ± 50**	228 ± 50	267 ± 56	368 ± 93♀♀♀	317 ± 33♀
Time on skill and agility task (s)	171 ± 36*	133 ± 28	154 ± 30	220 ± 69♀♀	193 ± 35♀
Time on strenuous task (s)	609 ± 115*	506 ± 93	559 ± 136	909 ± 239♀♀♀	708 ± 132♀♀♀
Time on puzzle (s)	173 ± 53**	127 ± 36	155 ± 37	160 ± 17	162 ± 20
Mean HR (beats/min)	161 ± 10**	171 ± 9	174 ± 15	173 ± 12	167 ± 7
Peak HR (beats/min)	182 ± 9**	191 ± 10	193 ± 12	191 ± 12	188 ± 13
cLa_B at the end (mmol/L)	8.9 ± 2.2	9.2 ± 2.2	9.4 ± 1.5	9.7 ± 2.4	10.1 ± 2.1
CR-10 at the end	5.4 ± 1.4[ff]	5.7 ± 1.5[ff]	8.1 ± 0.9	7.9 ± 1.8	7.4 ± 1.8
Air breathed (L)	1565 ± 319	1482 ± 191	1613 ± 226	1794 ± 348	1760 ± 335

Notes. *p < .05, **p < .01, ***p < .001 for senior versus young firefighters; ♀p < 0.05, ♀♀p < 0.01, ♀♀♀p < 0.001 for female versus male applicants; [ff]p < .01 for firefighters versus applicants. The data are M ± SD of the number of the participants. a = the 5 female applicant who fulfilled all formal requirements, b = one female applicant did not complete the test, HR = heart rate, CR-10 = ratings of perceived exertion measured with the Borg CR10 scale, cLa_B = blood lactate concentration.

3.4. Relationship Between Performance on Trondheim Test and NLIA Tests

3.4.1. Trondheim test versus extended NLIA treadmill test

When extending the NLIA treadmill test to exhaustion, the time on the Trondheim test could be predicted from the time to exhaustion with an error of 2 min (Figure 3a). Moreover, performance on the Trondheim test could also be predicted from peak V_{O2} during the extended NLIA test with an error of ≤3 min (Figure 3b). The performance was more closely related to peak V_{O2} in absolute values than expressed relative to the body mass or total mass carried (not shown).

3.4.2. Trondheim test versus NLIA strength tests

Performance on the Trondheim test correlated with the measured strength on all three strength tests and with the pooled strength index; the stronger participants were the fastest (Figure 4). However, there were considerable variations, and some participants whose strength was below the average, were among the fastest ones on the Trondheim test. Thus, the significant correlations were a consequence of fast participants performing well on the strength tests and some noticeably weak participants, in particular 2 women, who performed much below average on the Trondheim test.

3.5. Cut-off Score on Trondheim test

Time to exhaustion on the extended treadmill test was used to estimate performance on the Trondheim test. Regression analysis showed that participants who completed the Trondheim test in ≤19 min, met the standards set by the NLIA (Figure 3a, see the cut-off lines). All male participants, except 4 seniors and 1 applicant, completed the Trondheim test within the proposed time limit of 19 min. Two senior firefighters who did not, also failed on the 8 min treadmill test (Figure 3a). The slowest senior, who walked for 14 min on the extended NLIA treadmill test (6 min more than required), weighed only 66 kg, which equals the mean of the 8 female applicants. On the strength tests he performed as the average firefighter. Four female applicants did not finish the Trondheim test within 19 min. Two of them

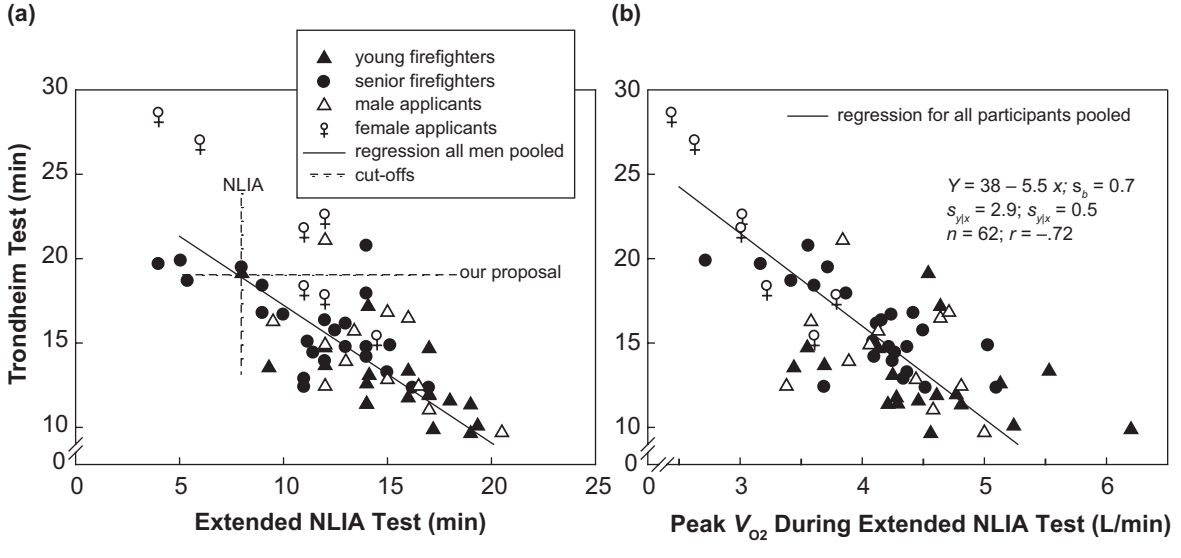

Figure 3. Relationships between time on Trondheim test versus scores on extended NLIA treadmill test. *Notes.* (a) time on the Trondheim test versus time to exhaustion on the extended NLIA treadmill test. The regression line was calculated from data of all men. The vertical dashed line is the lower accepted performance set by NLIA (cut-off), and the horizontal line is our proposed limit taken as the intersection between the regression line and NLIA's cut-off; (b) time on the Trondheim test versus peak V_{O2} on the extended NLIA treadmill test. The regression line was calculated from data of all subjects. $s_{Y|x}$, $s_{X|y}$ = errors of regression, s_b = error of the slope, r = correlation coefficient, NLIA = Norwegian Labour Inspection Authority.

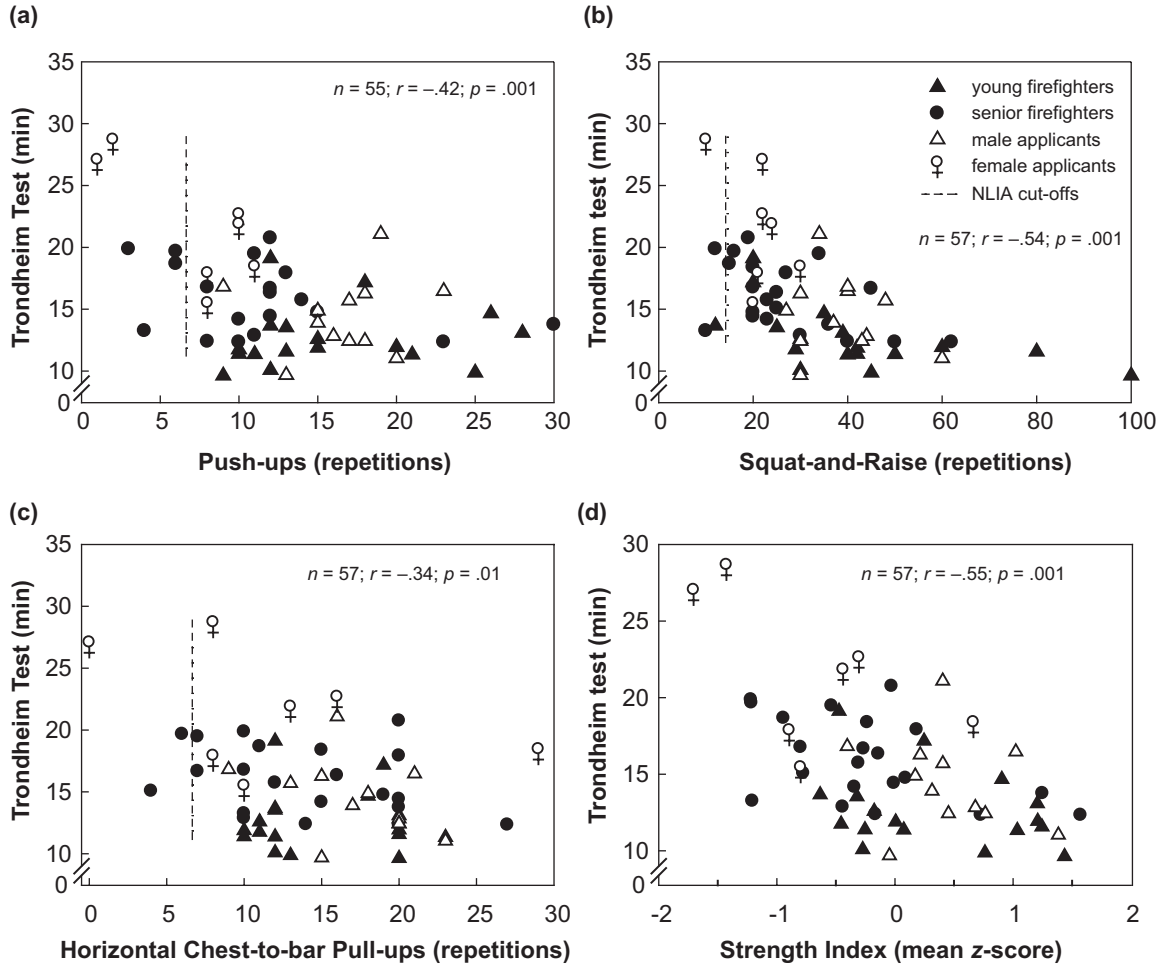

Figure 4. Relationships between performance time on Trondheim test versus scores on strength tests. *Notes.* (a) time on the Trondheim test versus maximum number of push-ups; (b) time on the Trondheim test versus maximum number of squat-and-raises; (c) time on the Trondheim test versus maximum number of horizontal chest-to-bar pull-ups; (d) time on the Trondheim test versus pooled strength index. The vertical dashed lines indicate the lower limits of acceptance (cut-offs) set by NLIA. *r* = correlation coefficient, NLIA = Norwegian Labour Inspection Authority.

carried out the Trondheim test in ≥27 min and also failed on the 8-min NLIA test and on the strength tests. The other 2 women, who needed ~22 min on the Trondheim test, completed the 8-min NLIA treadmill test and continued exercise at the extended test for additional 3–4.5 min; they also performed well on the strength tests.

4. DISCUSSION

The main result of this study is the close linear relationships between performance on the Trondheim test and scores on the extended treadmill test approved by the NLIA. The male participants with equal performance on the NLIA test performed equally on the Trondheim test irrespective of age and experience. However, the female participants, being smaller and weighing less, performed relatively poorer on the Trondheim test than on the NLIA treadmill test. Finally, performance on the Trondheim test was not closely related to the scores on the NLIA strength tests.

4.1. Trondheim Test Versus Extended NLIA Treadmill Test

The main aim of the Trondheim test was to examine firefigters and applicants in physically demanding fire fighting tasks that may be more relevant than the treadmill walking test. The time to complete the test was the outcome measure

and was closely related to the time to exhaustion on the extended NLIA test. Consequently, performance on the Trondheim test could be predicted from the time of the extended NLIA test, and vice versa, with moderate error. The Trondheim test may, therefore, be an alternative to the NLIA treadmill test. The proposed time limit in this study is 19 min.

The close relationship between performance on the extended NLIA test and on the Trondheim test shows that both tests are physically demanding and strenuous for firefighters. The close relationship between time to exhaustion at the extended NLIA test and peak V_{O2} suggests that $V_{O2\,max}$ is important for performance on the extended NLIA test. Thus, data in the present study show that $V_{O2\,max}$ may also be important for the Trondheim test. Aerobic power is probably a major limiting factor for a firefighter's ability to complete job-related tasks. However, this issue needs a close examination and direct verification.

Other studies also found significant correlations between performance on laboratory and job-related tasks [15, 24, 31]. However, the test protocols were different. Moreover, Rhea, Alvar and Gray did not find significant correlations between aerobic fitness tests and fire fighting tasks [22]. Their study measured aerobic fitness with a 12-min run, without turnout gear, while the fire fighting tasks lasted only ~1 min. Von Heimburg, Rasmussen and Medbø found a significant relationship between $V_{O2\,max}$ measured during a treadmill running test and performance time during strenuous rescue work [5], but there were large residual variations. The results of these studies suggest that although aerobic power is an important factor for performance on fire fighting tests lasting several minutes, other factors not measured with general tests are also important.

Performance on the extended NLIA test is closely related to peak V_{O2} expressed relative to the total mass carried. However, performance on the Trondheim test is more closely related to peak V_{O2} in absolute values. This suggests that bigger participants performed better on the Trondheim test than on the NLIA treadmill test. Thus, as discussed further, smaller women performed worse on the Trondheim test. Moreover, well-built firefighters performed better when rescuing patients at a hospital [5]**.** These considerations suggest that the Trondheim test might be more relevant for testing firefighters than the NLIA test.

There are no data on anaerobic energy release apart from high blood lactate concentrations. This is not a major problem since the anaerobic contribution is relatively small for exercise lasting many minutes even when the blood lactate concentration is high (see, e.g., Medbø [32] for a recent review).

4.2. Further Aspects of Trondheim Test

The measured HR during the test shows that exercise in the heat chamber (part 2) was particularly physically demanding. For the participants who completed the Trondheim test in ≤19 min, part 2 of the test took ~37% of the total time, irrespective of background (age, fire fighting experience). Less fit participants, who needed over 19 min to complete the test, spent disproportionately more time in the heat chamber. So did all but one woman, irrespective of performance time. Physical work in the heat may distinguish physically fit and less fit participants. However, after ~7 min of exercise in the heat (37% of 19 min), the participant got hot and, therefore, had to slow down the pace.

Some tasks on the Trondheim test were classified as requiring skill and agility but not as being physically demanding. These tasks took only ~17% of the total performance time, and all participants spent roughly the same amount of their total time on these tasks. Consequently, slower and probably less fit participants spent more time even on these tasks, too. It is not clear why physically less fit participants spend more time on tasks that are not physically demanding. The reason could be that less fit participants work slower to get more time to recover before the next physically demanding task. Another reason could be that less fit participants fatigue easier and earlier; their slower performance on skill and agility tasks could be a consequence of fatigue.

The Trondheim test includes a mental test in the form of solving a simple puzzle. The study shows that the young firefighters completed the puzzle faster than the senior firefighters. Some

senior firefighters reported blurred vision through the mask at short distance because they were farsighted. Thus, this part of the test may discriminate because of age. Consequently, more relevant mental tests for firefighters should substitute solving the puzzle in the Trondheim test.

The senior firefighters did not perform as well as the younger men, either on the whole test or at the skill and agility tasks. Their poorer performance was a consequence of poorer physical ability since men of the same physical fitness level performed similarly on the test irrespective of age and experience. Years of experience do not improve performance on the Trondheim test. The results of the present study disagree with those of Louhevaara, Soukainen, Lusa, et al., who proposed that senior firefighters were able to compensate for reduced aerobic power with better skills during fire fighting tasks [15].

If the Trondheim test requires experience, the applicants' performance should be worse. Pandorf, Nindl, Montain, et al. found a 9% improvement from the first to the second trial on a repetitive box-lifting task [33]. In the present study, no differences were found in performance on the Trondheim test between the experienced firefighters, who were familiar with the test, and the applicants walking for the same duration on the extended treadmill test. The results suggest that tasks in the Trondheim test were easy to perform, even for beginners. Thus, possible demands for technical skills may not be an argument against using the Trondheim test even for applicants.

4.3. Trondheim Test Versus NLIA Strength Tests

Performance on the strength tests varied considerably. The young men performed better than the senior firefighters and the women. Performance on the Trondheim test correlated with those of the strength tests, but there were large residual variations. Thus, the statistically significant correlations are a consequence of a few inadequately fit women failing on several tests and some stronger than average fast firefighters. Therefore, women may fail on the Trondheim test because of insufficient muscle strength, but muscle strength beyond a certain minimum does not seem to improve performance on the Trondheim test. These considerations may be simplistic.

At the NLIA strength tests, participants lift their own body mass. Thus, the required force is higher for heavy participants than for light ones. During the Trondheim test, all participants dragged the same 32-kg firehose, lifted the same 18-kg concrete blocks and carried the same 23-kg cans. These tasks are relatively more demanding for light than for heavy participants. Nevertheless, the results of the present study suggest that the Trondheim test may not be an alternative to the strength tests required by NLIA.

The conclusions of the present study are at variance with results of several other studies that have related muscle strength to performance on fire fighting tasks [21, 22, 23, 24]. In these studies, stronger participants with high scores on muscular endurance performed fire fighting tasks faster than weaker participants. However, in each example, the correlations were moderate and reflected large residual variations (~2 min for 6-min tasks). Moreover, the duration of the examined tasks varied between ~1 min [22, 23] and 5–7 min [21, 24]. V_{O2max} may not be essential for tasks lasting only 1 min and involving only medium-sized muscle groups. High muscular strength and endurance of these participants may also indicate a generally high fitness level.

The NLIA strength tests do not test strength in back and abdominal muscles. For the present study, where the characteristics of the Trondheim test were important, this was not a problem. However, fire fighting includes lifting and working with heavy tools, which involve back and abdominal muscles. Strong core muscles may protect against several musculoskeletal problems. Thus, the NLIA tests should include strength tests for body muscles.

4.4. Possible Gender Effects

Fire fighting traditionally has been men's job, not only because of the physical requirements. The principle of equal status between genders requires that physically fit women should not be excluded as firefighters only because of their gender. In the present study, the female applicants performed poorer than the men on most tests. Moreover, for

the same performance time on the extended NLIA test, the women needed more time on the Trondheim test than the men. The reason for this difference is not known. It could be that their lower body mass and muscular strength was a disadvantage for the women at the Trondheim test but not at the NLIA tests. Data on the lightest senior firefighter (66-kg male) supports this conclusion. His $V_{O2\,max}$ was 53 ml/kg/min, he was able to walk for 14 min at the extended NLIA treadmill test but he was the slowest man on the Trondheim test. This might suggest that his low body mass was a disadvantage on the Trondheim test. Low body mass and muscle strength was also a limiting factor for women in other studies examining fire fighting tasks [4, 34]. Women with high $V_{O2\,max}$ may perhaps compensate for low muscle strength [1].

Slow participants, including the women, also needed more time on skill and agility tasks. The women had less experience with heavy practical work tasks than the men. Contrary to the previous suggestions, experience may be important on the Trondheim test. These results correspond with other results which also found that women performed poorer on physical tests than men [18, 35, 36]. Women's poorer performance was more pronounced for job- specific tasks than for simple endurance and strength tests. Moreover, more practice may improve the women's performance [35].

The women needed more time in the heat chamber than the men. Because the women needed over 19 min for the whole test, distinguishing possible gender differences and effects of test duration on the proportion of time spent in the heat chamber is impossible. However, in the heat chamber, hanging 18-kg concrete blocks on hooks 1.85 m above the floor was an essential task. For tall and strong men, lifting the blocks was not a major challenge but it was so for shorter women with weaker arms and shoulders; most women used one concrete block as a one-step staircase to reach the hooks. Placing, climbing, moving and dismounting these staircases took extra time and effort. Lowering the height of the hooks would ease the task for women. It is not known whether the ability to repeatedly lift heavy items above the shoulders is essential for a firefighter. These considerations suggest that the Trondheim test may need a content validation and redesign to test women as possible smoke divers.

4.5. Appropriate Tests and Requirements

At the end of the 8-min NLIA treadmill test, V_{O2} was ~32 ml/min/kg total mass carried (body mass + 23 kg), which is the aerobic demand of this test. For the average man weighing 84 kg, this result corresponds to V_{O2} of 3.4 L/min (41 ml/min/kg body mass), while for the average woman weighing 66 kg, it corresponds to 2.9 L/min (43 ml/min/kg body mass). Therefore, $V_{O2\,max}$ must be at least 32 ml/min/kg total mass carried. Thus, the participants with $V_{O2\,max}$ of 3–3.5 L/min (40–45 ml/min/kg) or less will not be able to complete the treadmill test and will not qualify to be smoke divers in Norwegian fire brigades. This minimum aerobic demand is in line with the suggested minimum standard of 40–45 ml/min/kg of other studies [1, 2, 3, 7, 11, 12, 13, 14, 15, 16, 17]. In their previous study, the authors of this paper suggested that to perform rescue work at a hospital, a male firefighter should have $V_{O2\,max}$ of at least 4 L/min [5]. The difference between these proposed minimum values is moderate. As a further note, a parallel study has shown that the O_2 uptake averages 35 ml/min/kg during the Trondheim test [37].

Because each test is adapted to one specific place, it may be difficult to compare the results of similar tests set up at different places [15, 38, 39]. The present Trondheim test is no exception. Consequently, establishing a minimum requirement on the tests may be a problem. By comparing the outcome with a standard approved test, as done in the present study, that problem may be overcome.

Because the NLIA approved test is chosen as the national norm, the Trondheim test seems to discriminate against women. Tasks in the heat chamber may be particularly discriminating. However, while the NLIA test is a simple treadmill test with moderate relevance for firefighters, the Trondheim test includes a number of fire fighting tasks. Therefore, the Trondheim test may

be more relevant for testing firefighters. If so, it could be argued that the NLIA test favours females. There is no standard for testing firefighters. Therefore, it cannot be said to what extent the Trondheim test discriminates women or the NLIA treadmill test favours women.

4.6. Practical Applications and Conclusions

Valid information on using work-related tests for measuring fitness is necessary. Because the Trondheim test distinguishes aerobically fit and less fit firefighters and applicants, it may be used as an alternative to the NLIA treadmill test. However, women's performance on the Trondheim test compared with the NLIA test was poorer than men's; women would consequently benefit on the NLIA treadmill test. Tests simulating real work are more relevant and with better motivation; they also give the leaders information about skills and agility that is not tested with simple laboratory tests. Performing both test every year to test firefighters' capabilities may be a compromise. The results may give leaders information on the cardiovascular fitness level and the work efficiency of the individual. The combined test could provide additional information helping establish optimal training for each firefighter. The Trondheim test may be useful for testing new firefighters because the results of the test do not depend on firefighter's experience. However, because women are at a disadvantage on the Trondheim test, it needs to be redesigned to avoid possible gender discrimination.

The Trondheim test may be an alternative to the NLIA treadmill test. The data of the present study suggest that the applicant should complete the whole test within 19 min to be accepted as a smoke diver. The Trondheim test may discriminate against women and further examinations are necessary. The Trondheim test cannot substitute the strength tests required by NLIA.

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