

Self-Rated Physical Loads of Work Tasks Among Firefighters

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Objectives. The present study sought to identify firefighters' rated physical demands for the most frequently occurring work tasks and to determine if the ratings differed between full-time and part-time firefighters to help create a basis for the development of physical employment tests for firefighters. **Methods.** An extensive questionnaire was completed by 125 and 68 firefighters in 2000 and 2010, respectively. The data were analysed with the Mann–Whitney U test and binominal test and ranked on the basis of the responses in each category. **Results.** Significant differences were seen between the full- and part-time firefighters. The work tasks rated as the most physically strenuous in terms of aerobic fitness, muscle strength, work posture and body control by most respondents were smoke diving upstairs (carrying a hose), victim rescue in different ways, carrying a stretcher over terrain and pulling a hose. **Conclusions.** Physically strenuous work tasks should be included in the end-point performance variables used to select physical performance tests for firefighters. The part-time firefighters with no experience in several of the work tasks suggests that work-related exercises are important if both groups of firefighters are expected to do similar work.

emergency personnel ergonomics physical demand performance tests

1. INTRODUCTION

Working as a firefighter is very risky and employees have to be well prepared for the job. The physical training status [1, 2], anthropometrics [2, 3, 4], body balance [5], flexibility [3], lag time (the time from an incoming call to departure of service vehicles) [6] and preparation of the emergency vehicles [7] affect the firefighter's work performance. Correlations between work performance and isolated physical capacities have been investigated

for different types of firefighting activities, including navy shipboard firefighting [8], the pack hike test [9, 10, 11] and rescuing hospital patients [2]. Work task courses, which include several work tasks such as climbing stairs, carrying equipment, raising and extending a ladder, forcible entry, searching, ceiling breach and pulling, rescue dragging, and advanced hose pulling have also been investigated [3, 4, 12, 13, 14, 15, 16]. The most frequently measured parameter in these work tasks is oxygen uptake

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(V_{O_2}). Reported metabolic demands (relative oxygen uptake in relation to the body weight) in some of these studies ranges from 16 to 55 ml/kg/min depending on the work task and the pace of the work performed. Smoke diving with breathing apparatus (BA) firefighting [13, 16, 17] and victim rescue [4, 18] have been reported to be two of the most physically demanding work tasks in terms of aerobic fitness. In the last decades, lightweight BA has been introduced, which may reduce the metabolic demands. Muscle strength is also important for firefighters' work performance [3, 12, 14, 19, 20], but it is difficult to compare these studies due to the wide range of physical tests.

Swedish fire and rescue services in small municipalities more often hire part-time than full-time firefighters compared to larger cities but both groups perform the same work tasks (excluding specific high-risk tasks). The Swedish Work Environment Authority Act defines the required physical ability of Swedish firefighters who use BA [21]. This physical capacity is tested with an aerobic exercise test on a treadmill. A candidate must pass both a health check-up and exercise tests to be certified for smoke diving. Each municipality selects from a variety of physical tests throughout the country additional physical tests for firefighters. The present study was conducted on the Swedish Civil Contingencies Agency's request to serve as the basis for developing new pre-employment tests and their physical requirements that will be valid for the Swedish fire and rescue services. A standardized battery test is important to ensure the equal work capacity of all firefighters throughout the country. Therefore, the aims of the present study were to identify firefighters' rated and ranked physical demands for the most frequently occurring work tasks and to determine if there were any differences in the ratings between full- and part-time firefighters.

The physical capacity to perform a work task must be weighed against the frequency at which the task is performed to balance the collective performance of any work force. Some studies suggest that readiness should be maintained only for common work tasks that are at the same

time physically demanding [16, 22, 23, 24]. According to Phillips, Payne, Lord, et al., it is important to first identify the most physically demanding work tasks and then to investigate the frequency at which they are performed [9]. Otherwise, physically demanding tasks might mistakenly be omitted because they are performed less frequently and thus not classified as critical. Previously, Gledhill and Jamnik [16], and Lusa, Louhevaara and Kinnunen [25] constructed questionnaires where firefighter's physical demands and work task frequencies were rated in their respective countries. These two studies found that carrying equipment upstairs, advancing charged hose, smoke diving with BA, clearing debris and roof work were among the most physically demanding work tasks [16, 25]. Sothmann, Gebhardt and Baker clustered 233 tasks into 11 relevant groups but without reporting specific tasks within each group [26]. This resulted in useful overall information but lacked specificity in terms of the tasks that were included. A recent study has identified physically demanding tasks and their frequencies among rural firefighters in Australia using semi-structured group interviews, but these results might not be applicable to other rescue services [9]. No recent studies have investigated the physical demands applicable for general firefighting and rescue services nor have any studies compared ratings of physical demands between full- and part-time firefighters. The present study, therefore, is intended to provide a basis for the future development of valid physical performance tests that are applicable for all firefighters.

2. METHODS

2.1. Questionnaire Design

A questionnaire developed for this study focused on the physical effort required for a wide range of work tasks relevant for a firefighter. It was the first step in the selection of valid physical tests for Swedish firefighters. By identifying the most physically demanding tasks among those that are performed most frequently, the most important

work tasks can be selected for further studies using objective measures of physical demands. The questionnaire was developed in 2000 and was based on Swedish and international reports on work tasks and physical requirements [16, 25, 27, 28] and on interviews with a representative group of employees within the Swedish rescue services. The questionnaire was sent to 40 firefighters in a prestudy (response rate 92%) that evaluated the frequencies and physical efforts required for 50 work tasks grouped into seven clusters. After evaluation and adjustments, the final version of the questionnaire included the same seven clusters (Table 1) as in the prestudy, but the work tasks that had been the least demanding were removed to shorten the questionnaire and reduce the risk of not being answered by the firefighters. Consequently, some work tasks were represented only within one cluster and some work tasks were represented within several clusters. The prestudy data is not reported in the present study.

The finalized questionnaire included both rated and ranked response options and was sent to firefighters for the first time in 2000. Due to the long time between the questionnaire in year 2000, the continuing work with finding valid physical tests and stating accepted physical requirements, the questionnaire was sent out for the second time in 2010. Data from both years (2000 and 2010) are included in the present study. The individual and occupational characteristics registered in the sur-

vey included age, gender, employment type (full- or part-time), years of employment, if BA firefighting was performed and, if so, the number of years as a BA firefighter.

2.1.1. Rated questions

In the five clusters of the questionnaire, the respondents rated the physical effort of work tasks according to their own experience with pre-defined rating options. The difficulty of the tasks in terms of required aerobic capacity were rated as *very easy, easy, somewhat hard, hard, very hard* or *I don't know*. Requirements for muscle strength in the hands, arms, trunk, and legs were rated as *low, rather low, high, very high* or *I don't know*. The respondents were instructed to answer *I don't know* if they had no experience with a work task. The rating options were set so as to reflect a wide variety of perceived physical effort. The term *I don't know*, in figures and in the text, also means *no experience*.

2.1.2. Ranked questions

In the two clusters of the questionnaire, the respondents ranked work tasks in descending order within each of the two physical requirements requested. In 2000, work tasks were ranked from the most demanding (ranking 1) to the least demanding task (ranking 5) with the option of giving equal rankings to several work tasks. To avoid misinterpretations in the later

TABLE 1. Characteristics of Questionnaire

Topic	Question	Task
Rated		
aerobic	How strenuous do you experience the following work tasks (exercise and alarms) to be in terms of your aerobic fitness (oxygen uptake, aerobic capacity, "panting")?	31
hand strength	Please rate how much hand strength you feel that the following work tasks require.	28
arm strength	Please rate how much arm strength you feel that the following work tasks require.	30
trunk strength	Please rate how much trunk strength (back, chest, abdomen) you feel that the following work tasks require.	25
leg strength	Please rate how much leg strength you feel that the following work tasks require.	17
Ranked		
posture	Please rank the following work tasks from the most (1) to the least (18) demanding work posture requirements.	18
body control	Please rank the following work tasks from most (1) to the least (14) demanding body control (balance and co-ordination) requirement.	14

survey, the ranking questions were changed in 2010 and the respondents were asked to rank all work tasks within each cluster from the most to the least demanding. Consequently, only ranking data from 2010 are presented and comparisons between full- and part-time firefighters were not made for these questions.

2.2. Respondents

The Fire Rescue Services of the same 32 municipalities were invited to participate in the questionnaire in 2000 and 2010. Municipalities were selected on the basis of population density, location and emergency/alarm statistics [28]. The smallest municipality had under 5000 inhabitants and the largest had over 100 000. The questionnaire was distributed to 32 (160 firefighters) and 28 (84 firefighters) municipalities in 2000 and 2010, respectively. The Research Ethics Committee for Northern Sweden at Umeå University approved the study.

2.3. Data Analysis

2.3.1. Statistics

SPSS version 20.0 was used for statistical calculations. Comparisons of individual and occupational characteristics between 2000 and 2010 were performed with independent sample *t* tests and the Mann–Whitney *U* test. A binominal test analysed differences in respondent group distribution. The probability level of acceptable significance was .05.

Comparisons of the distribution of answers within rating data between 2000 and 2010 were analysed with the Mann–Whitney *U* test and adjustments for multiple comparisons used the Bonferroni correction. The null hypothesis that the distribution of answers was similar in 2000 and 2010 was retained and data from 2000 and 2010 were merged in all analyses of the rating data.

The rated work tasks were manually ranked in descending order within each physical effort on the basis of the number of responses in the highest ordinal response (*very hard* for aerobic capacity and *very high* for muscle force) and without separating responses from full- and part-time firefighters.

Differences in the distribution of answers between respondent groups within each rated work task were analysed with the Mann–Whitney *U* test. Adjustments for multiple comparisons used the Bonferroni correction. The null hypothesis was that the distribution of answers would be the same for both groups. Distribution of each response was analysed with the binominal test if there were significant differences.

The ranking topics were presented as the median (lowest and highest) ranking for each work task and manually ranked in ascending order without separating responses from full- and part-time firefighters. Presented data are for 2010 only.

3. RESULTS

3.1. Respondents

The response rate of the 160 questionnaires distributed in 2000 was 78% ($N = 125$). The response rate of the 84 questionnaires distributed in 2010 was 81% ($N = 68$). The mean age was 39.7 years (range: 20–60). The mean years of employment was 13.6 years (range: 1–38) and the mean years as a BA firefighter was 13.1 years (range: 0–38). The distribution of full- and part-time firefighters replying to the questionnaire was the same for both years (54% and 46% in 2000, and 53% and 47% in 2010), $U = 4278$, $z = 0.087$, $p = .93$, with more part-time firefighters in municipalities under 5000 inhabitants, $U = 700$, $z = -5.040$, $p < .001$. The inclusion of BA firefighters was higher than the inclusion of non-BA firefighters ($p < .001$) (98% and 2% in 2000, and 96% and 4% in 2010), without differences between 2000 and 2010, $U = 4370$, $z = 1.172$, $p = .24$. The distribution of men and women was the same for both years (94% and 6% in 2000, and 91% and 9% in 2010), $U = 4353$, $z = 0.618$, $p = .54$, with more male firefighters ($p < .001$).

3.2. Rated Physical Demands

3.2.1. Aerobic capacity

Victim rescue during BA firefighting, victim rescue (movement 30 m) and hose pull were among

the tasks rated as *very hard* by most respondents in terms of aerobic fitness (aerobic capacity). Significant differences ($p < .05$) between respondents groups were found in 19 of the 31 rated work tasks (Figure 1). Within the same work tasks, more part-time firefighters rated them as *I don't know* and more full-time firefighters rated them as *somewhat hard*, *hard*, or *very hard* ($p < .05$) (Figure 1).

3.2.2. Muscle strength requirements

Most respondents rated carrying a stretcher over terrain as requiring *very high* hand, arm, leg and trunk muscle strength, within all clusters of rated muscle strength requirements (Figures 2–5). Hose pull and victim rescue were also rated as requiring *very high* hand, arm, leg and trunk muscle strength.

Significant differences ($p < .05$) between respondent groups were found within all clusters of rated muscle strength (hands: 5/28 tasks, arms:

8/30 tasks, legs: 4/17 tasks and trunk: 10/25 tasks). These differences were most frequently caused by a combination of a higher proportion of part-time firefighters responding *I don't know* and a higher proportion of full-time firefighters responding *high* or *very high* within the same work tasks ($p < .05$). The work tasks making holes in the roof for fire-gas ventilation (hands), hose pull (arms) and external building firefighting (arms, legs, and trunk) were rated as requiring higher muscle strength among full-time than part-time firefighters ($p < .05$) without any differences in the *I don't know* response (Figures 2–5).

3.2.3. Ranked work posture requirement

Victim rescue during BA firefighting was ranked as the most strenuous work task (number 1 of 18 work tasks) by 54% of the respondents. Work tasks ranked as requiring the least work posture were forcing doors, and dragging and pulling material with a rope (Figure 6).

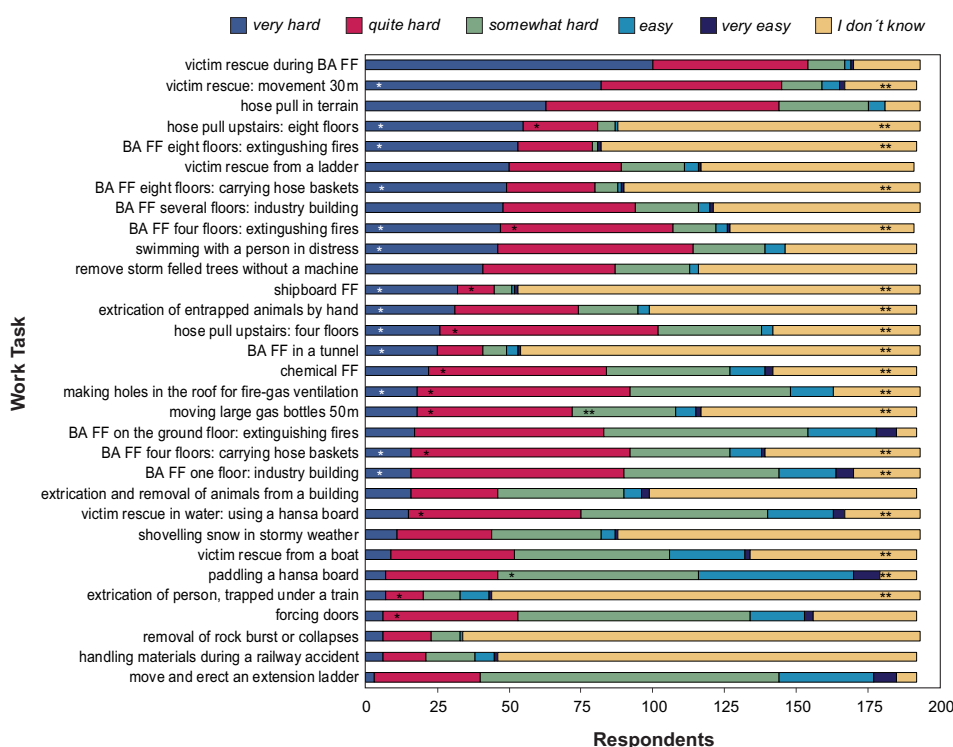


Figure 1. Aerobic fitness of work tasks. Notes. Work tasks are ranked in descending order starting with the task receiving the highest number of responses (N) in the highest ordinal response (*very hard*). BA = breathing apparatus, FF = firefighting, * = significantly higher number of full-time compared to part-time firefighters ($p < .05$), ** = significantly higher number of part-time compared to full-time firefighters ($p < .05$).

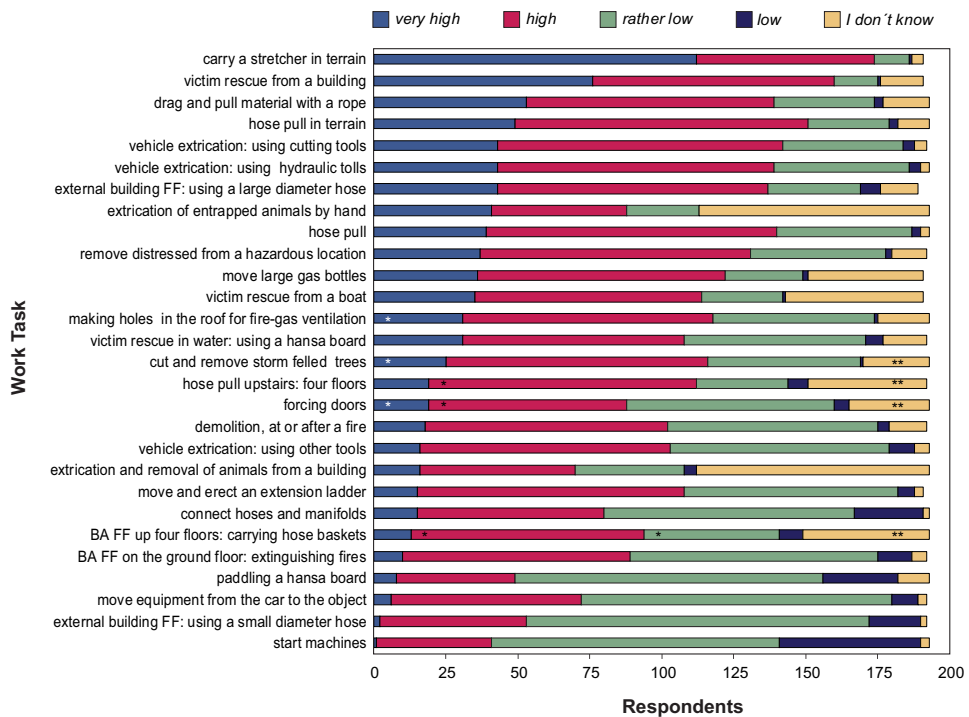


Figure 2. Requirements of hand muscle strength. Notes. Work tasks are ranked in descending order starting with the task receiving the highest number (*N*) of responses in the highest ordinal response (*very high*). BA = breathing apparatus, FF = firefighting, * = significantly higher number of full-time compared to part-time firefighters ($p < .05$), ** = significantly higher number of part-time compared to full-time firefighters ($p < .05$).

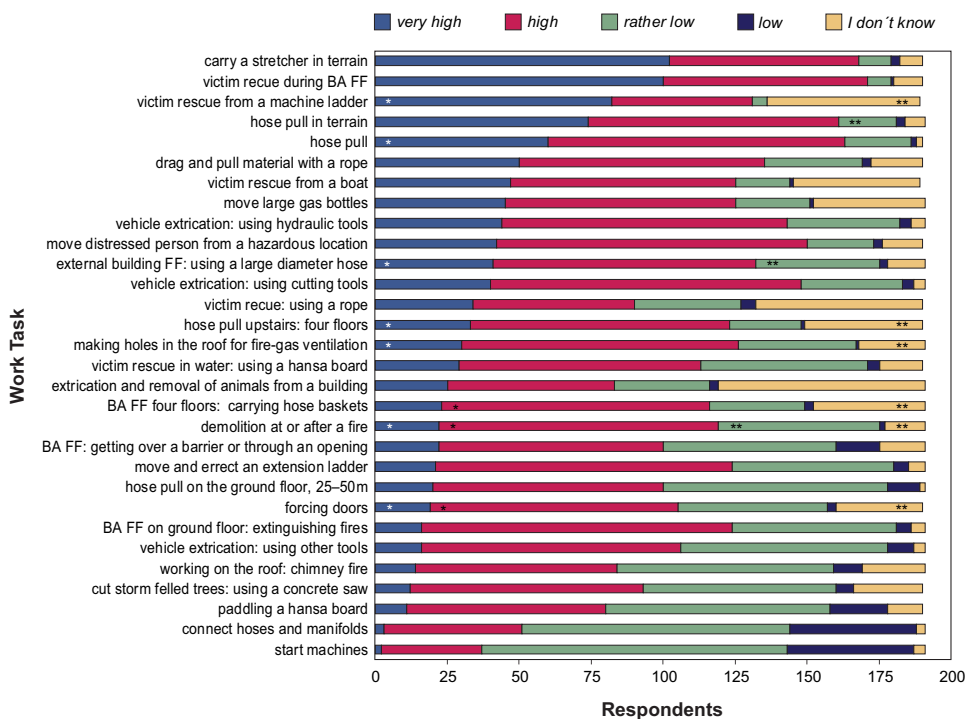


Figure 3. Requirements of arm muscle strength. Notes. Work tasks are ranked in descending order starting with the task receiving the highest number (*N*) of responses in the highest ordinal response (*very high*). BA = breathing apparatus, FF = firefighting, * = significantly higher number of full-time compared to part-time firefighters ($p < .05$), ** = significantly higher number of part-time compared to full-time firefighters ($p < .05$).

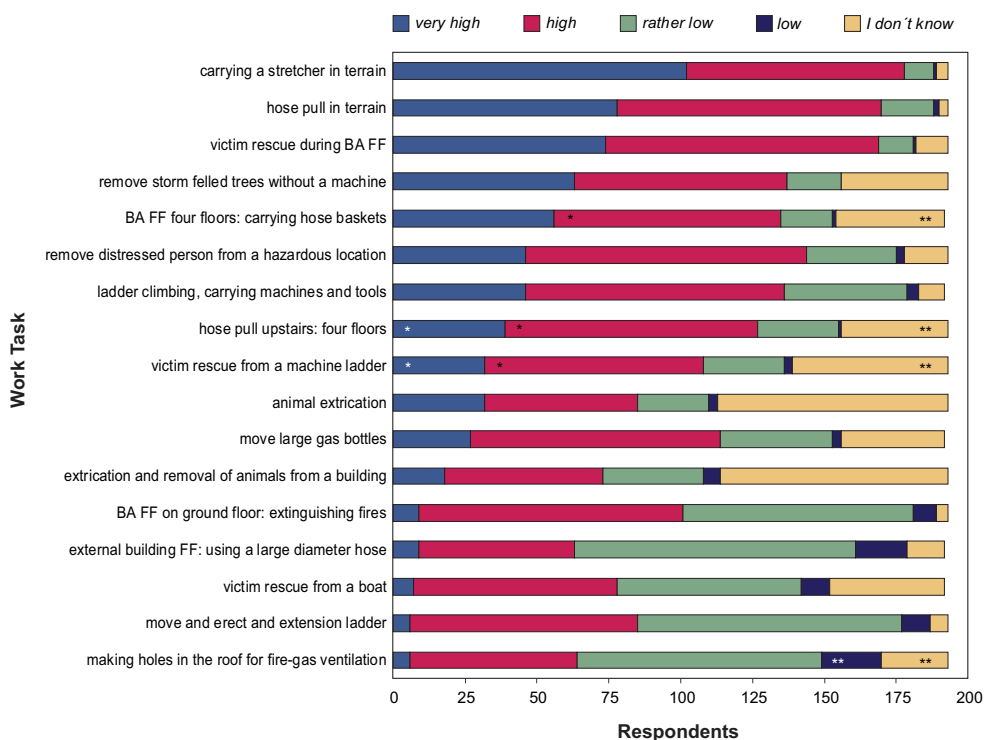


Figure 4. Requirements of leg muscle strength. Notes. Work tasks are ranked in descending order starting with the task receiving the highest number (N) of responses in the highest ordinal response (*very high*). BA = breathing apparatus, FF = firefighting, * = significantly higher number of full-time compared to part-time firefighters ($p < .05$), ** = significantly higher number of part-time compared to full-time firefighters ($p < .05$).

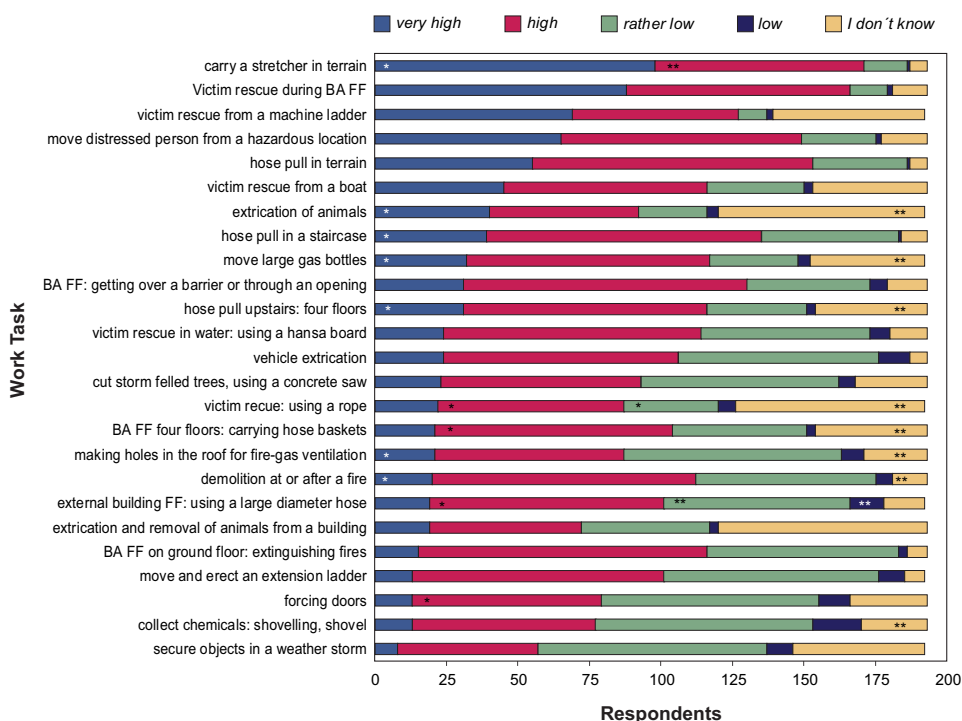


Figure 5. Requirements of trunk muscle strength. Notes. Work tasks are ranked in descending order starting with the task receiving the highest number (N) of responses in the highest ordinal response (*very high*). BA = breathing apparatus, FF = firefighting, * = significantly higher number of full-time compared to part-time firefighters ($p < .05$), ** = significantly higher number of part-time compared to full-time firefighters ($p < .05$).

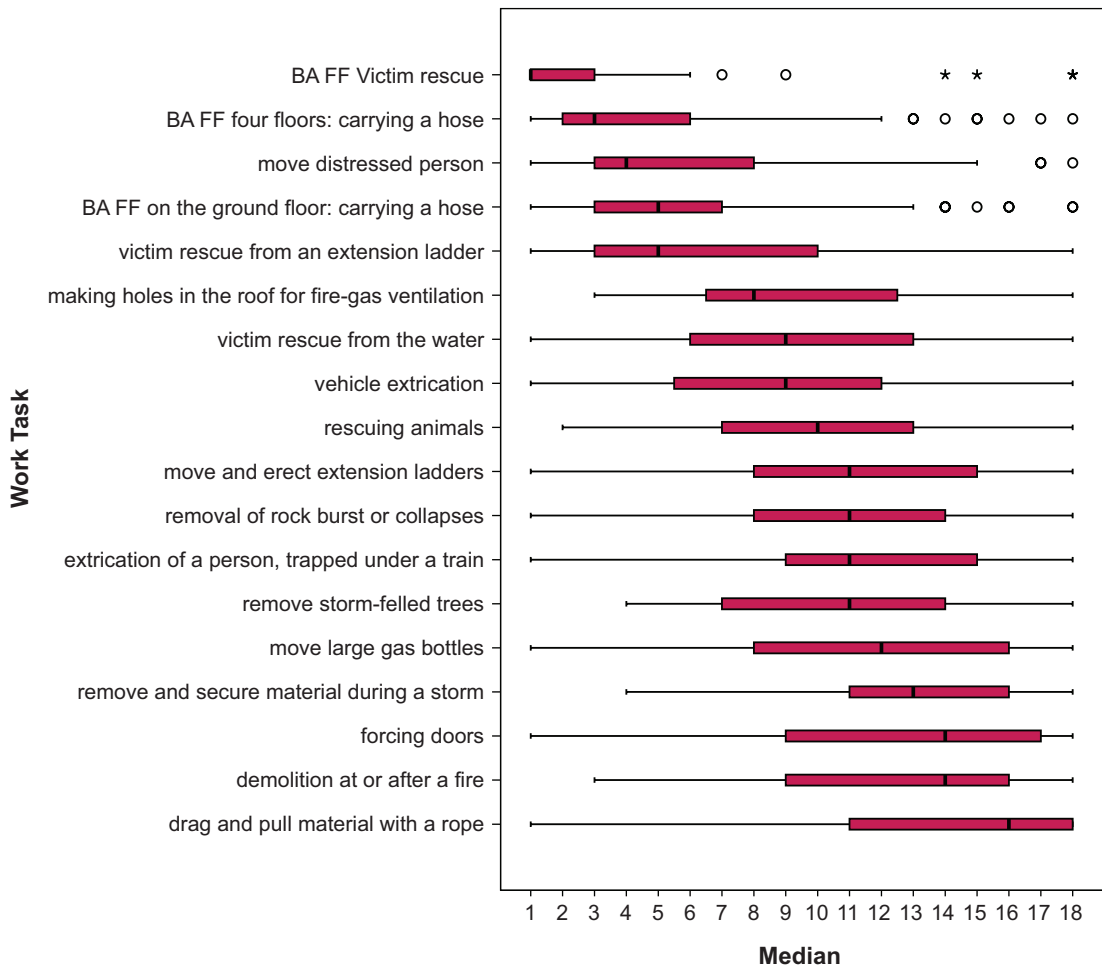


Figure 6. Posture requirements for work tasks. Notes. Data are presented as the median (line within the box) and lowest and highest values (left and right line from the box, outliers excluded (o *). Work tasks are ranked in descending order starting with the tasks ranked as most demanding. BA = breathing apparatus, FF = firefighting. Presented data are for the year 2010 only.

3.2.4. Ranked body control requirement

The median ranking of work body control requirements in 2010 ranged from 3.0 to 13.5 among both respondents groups. External victim rescue with an extension ladder was ranked as the most strenuous work task (number 1 of 14 work tasks) by 38% of the respondents (Figure 7). Work tasks ranked as requiring the least body control were removing storm-felled trees and demolition at or after a fire.

4. DISCUSSION

4.1. Physical Requirements

The results of this study indicate that smoke diving (working with BA); i.e., climbing stairs, carry-

ing a hose and victim rescue, carrying a stretcher over terrain, vehicle extrication, and hose pull, should be included among the end-point performance variables when developing tests of physical performance for firefighters. There were no significant differences in rated physical requirements between 2000 and 2010 indicating that any alternations in work equipment and rescue methods during these 10 years did not result in differences in physical loads on Swedish firefighters. For example, higher physical demands with heavier equipment are well known [29, 30] yet self-contained breathing apparatuses with heavy steel cylinders are sometimes used despite the existence of lightweight composite cylinders.

The physical capacity to perform a task depends on the rate, duration and environment of

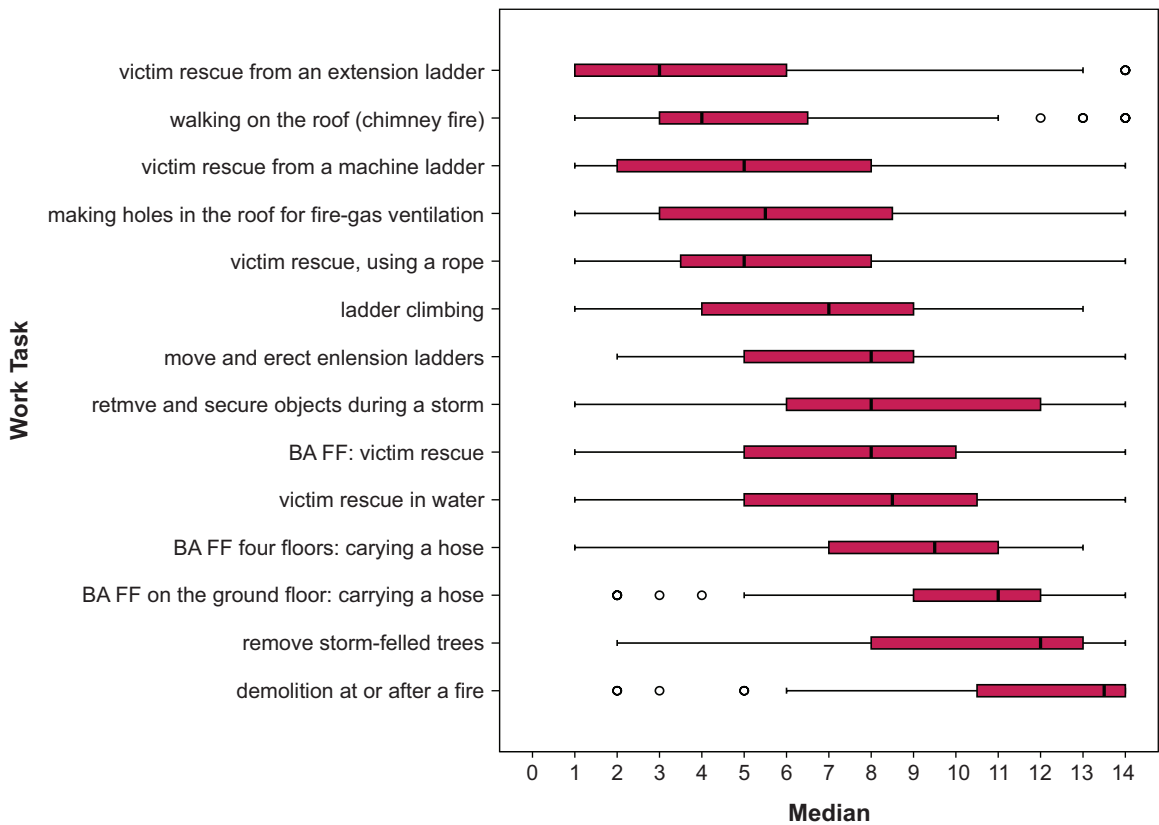


Figure 7. Body control requirements for work tasks. Notes. Data are presented as the median (line within the box) and lowest and highest values (left and right line from the box, outliers excluded (o)). Work tasks are ranked in descending order starting with the tasks ranked as most demanding. BA = breathing apparatus, FF = firefighting. Presented data are for the year 2010 only.

the performed work task. Consequently, any rated or ranked results are biased depending on the individual’s perceived workload, willingness to work until exhaustion, climate acclimatization, etc.

The work of a firefighter requires high V_{O_2} ; a demand confirmed in the present study in which numerous work tasks are rated to be *hard* or *very hard* in terms of aerobic fitness. Interestingly, Harvey, Kraemer, Sharratt, et al. reported no correlations between completion time on a task course and absolute (ml/min) ($r^2 = .18$, $p > .05$) or relative (ml/kg/min) ($r^2 = .04$, $p > .05$) $V_{O_{2max}}$ [20]. However, Bilzon, Scarpello, Smith, et al. suggested a minimum relative $V_{O_{2max}}$ of 41 ml/kg/min for shipboard firefighting [8]. Shipboard firefighting was rarely performed among the respondents in the present study and rated as *very hard* in terms of aerobic fitness by 56% of the respondents. The work tasks rated as requiring the highest aerobic fit-

ness in the present study have also previously been physically demanding for firefighters [4, 13, 14, 16, 17, 18]. However, it is difficult to determine the importance of specific physical capacities when judging performance by a task-course finishing time due to intercorrelations of capacities and the possibility of compensating for one physical capacity with another. This could explain the lack of correlation observed by Harvey et al. [20]. Instead, each task must be analysed separately to find valid physical capacities for testing.

According to Swedish firefighters, several work tasks included in smoke diving (working with a BA) such as victim rescue, hose pull upstairs and carrying hose baskets upstairs demand *very high* aerobic fitness, over-all strength and work posture (Figures 1–6). Moreover, work tasks included in smoke diving such as victim rescue and carrying a hose were ranked as the most physically demanding for work posture

(Figure 6). These findings are in line with previous studies [13, 14, 16, 17, 25]. According to the results of the present study, smoke diving is one of the most demanding work tasks for firefighters, but no recent study has identified the specific tasks included in smoke diving, which firefighters rated as physically demanding. Instead, they have been assumed to be the most physically demanding work tasks performed by firefighters.

The physical demands for carrying a stretcher over terrain were high $V_{O_{2max}}$ [31] and muscle strength [31, 32], but this needs further attention to extend the investigation of correlations between work performance and simple physical tests, not tests for $V_{O_{2max}}$ performed in a laboratory. Physical tests, which are at the same time valid for measuring firefighters' work performance, increase the ability to perform relevant physical tests of firefighters and decrease costs. The demands for muscle strength, as rated by firefighters in the present study, are higher for carrying a stretcher over terrain than for any other work task (Figures 2–5).

In this study, the physical demands for working with cutting tools (vehicle extrication) were rated as the work tasks requiring both very high hand and arm muscle strength (Figures 2–3) and body posture (Figure 6). Physical demands for vehicle extrication have not been well investigated and, as for hose pull, specific tests should be developed. Correlations between the completion time of a work task course and hand muscle strength and endurance have been investigated [4, 10, 12]. These studies concluded that both hand muscle strength and hand muscle endurance are important for completion time on a task course. As reported in other studies, this study also found leg muscle strength to be a relevant factor for pulling and climbing work tasks [12, 15].

4.2. Differences Between Respondent Groups

The authors of this study did not find any study comparing the physical demands between full- and part-time firefighters, yet both groups of firefighters are expected to perform the same work tasks. There are differences in perceived effort and in experience between the respondent

groups. Interestingly, part-time firefighters rated perceived effort lower than full-time firefighters in tasks such as making holes in the roof for fire-gas ventilation (hands) (Figure 2), hose pull (arms) (Figure 3) and external building firefighting (arms, legs and trunk) (Figures 3–5). Several work tasks such as hose pull upstairs four floors and carrying hose baskets upstairs four floors (Figures 1–5) were rated *I don't know* by more part-time than full-time firefighters. If all groups of firefighters are expected to execute the same work tasks, sufficient training time for work-related exercises is important to maintain good skills. The results of this study raise a question whether full- and part-time firefighters are qualified to do the same work.

4.3. Questionnaire Design and Representativeness

The questionnaire was sent twice, in 2000 and in 2010, and included seven clusters of 14–40 work tasks each. After the prestudy (including 50 work tasks within each cluster), the most relevant tasks only were included in the final questionnaire. If the questionnaire is too long, the respondents might be fatigued and not pay close attention to all their answers. The reduced questionnaire included questions on the most important tasks only; this reduced the risk of bias due to respondents' fatigue. Although 193 firefighters all over the country, from municipalities representing varying size, geographical distribution and dominating type of fire and rescue objects, took part in the questionnaire, the rather low number of respondents can be considered as a limitation of the study. A higher number of respondents would increase power. The response rate was slightly higher in 2010, but the gender distribution was skewed in both years with only 6% (2000) and 9% (2010) of women. Consequently, women were included in the analysis but the genders were not compared. A higher proportion of women in the study would have been preferable, but this number represents the proportion of women among Swedish firefighters [33].

In accordance with Bos, Kuijer and Frings-Dresen [22], Gledhill et al. [16] and Lusa, Louhevaara, Kinnunen [25], but in contrast to Phillips,

Payne, Lord, et al. [9], the most physically demanding tasks were identified by combining two issues. The present study constitutes the first step in the development of physical performance tests for firefighters. All tasks included in a test course to evaluate physical performance must be valid [23, 24] and the next step will be making physiological measurements using the present study as a base.

Although Michaelides, Parpa, Thompson, et al. [3] found high rankings for the relevance of the seven work tasks included in their task course, they did not compare the results between different respondent groups. Because only seven work tasks were included in their questionnaire [3], the risk of missing relevant work tasks that should be included was quite high. The current and previous questionnaires are in many ways representative for several countries because similar work tasks were selected.

The present study used ranking options for two clusters within the questionnaire: work posture and body control. Ranking options may not be the optimal method for screening work task relevance because the result will only reflect the intragroup distribution. Instead, ratings using pre-defined options is a more appropriate method to use because this allows for comparisons between countries and between respondents groups to be made. The present study used rating options for five clusters within the questionnaire.

4.4. Conclusion

The present study identified the most physically demanding work tasks from those performed most frequently by Swedish firefighters. The main findings are that a higher proportion of part-time firefighters lack experience in several work tasks and that a few work tasks were rated significantly lower among part-time compared to full-time firefighters. These findings indicate that work-related exercises may be important to maintain good skills within all groups of firefighters.

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