STUDIES IN SPORT, PHYSICAL EDUCATION AND HEALTH

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"Me emme löydä lepoa muusta kuin ponnistuksesta, samoin kuin liekki on olemassa vain palaessaan."

-Henri Amiel-

ABSTRACT

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The purpose of this study was to analyze physical job demands in fire-fighting and rescue work and to develop and evaluate procedures for the assessment of fire fighters' physical work capacity. Five studies were performed to attain this goal. In the questionnaire study the respondents were 156 professional fire fighters with the mean age of 36 years. From 12 to 59 male fire fighters participated in the laboratory and field studies, and their mean age varied from 23 to 39 years. According to the questionnaire, the most demanding fire-fighting and rescue tasks on physical work capacity in terms of cardiorespiratory capacity, muscular performance and motor coordination were smoke-diving, which requires the use of full personal protective equipment, clearing tasks with heavy manual tools, and roof work, respectively. During the past five years, 83-88% of the fire fighters, regardless of age, had performed each of these tasks four times a year, on average. Smoke-diving imposed a heavy cardiorespiratory load. The mean oxygen consumption was 2.4 l/min corresponding to 60% of the maximal oxygen consumption. Heart rate averaged 150 beats/min, being 79% of the maximal heart rate. A biomechanically analyzed clearing task produced a high load on the musculoskeletal system, particularly according to the mean dynamic compressive force of 6228 N at the vertebral disc L5/S1. The amount of force was about equal in both young and aging subjects. The developed job-related treadmill test protocol and the work site test drill for the assessment of the cardiorespiratory work capacity of fire fighters for smoke-diving proved to be valid and feasible. The job demands on physical work capacity remained high during the occupational career of fire fighters. In practice, the cardiorespiratory work capacity of fire fighters for smoke-diving can be assessed reliably with the developed treadmill and work drill tests. The tests are necessary in the planning and carrying out of preventive measures for maintaining the work ability of fire fighters.

Key words: job demands, physical work capacity, fire-fighting and rescue work, heart rate, oxygen consumption, biomechanical features, age

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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals:

(I) Lusa, S., Louhevaara, V. & Kinnunen, K. 1994. Are the job demands on physical work capacity equal for young and aging firefighters? Journal of Occupational Medicine 36, 70-74.

(II) Lusa, S., Louhevaara, V., Smolander, J., Kivimäki, M. & Korhonen, O. 1993. Physiological responses of firefighting students during simulated smoke-diving in the heat. American Industrial Hygiene Association Journal 54, 228-231.

(III) Lusa, S., Louhevaara, V., Smolander, J., Kinnunen K., Korhonen, O. & Soukainen, J. 1991. Biomechanical evaluation of heavy tool-handling in two age groups of firemen. Ergonomics 34, 1429-1432.

(IV) Lusa, S., Louhevaara, V., Smolander, J., Pohjonen, T., Uusimäki, H. & Korhonen, O. 1993. Thermal effects of fire-protective equipment during job-related exercise protocol. SAFE Journal 23 (1), 36-39.

(V) Louhevaara, V., Soukainen, J., Lusa, S., Tulppo, M., Tuomi, P. & Kajaste, T. 1994. Development and evaluation of a test drill for assessing physical work capacity of fire-fighters. International Journal of Industrial Ergonomics 13, 139-146.

ABBREVIATIONS

ECG	=	electrocardiogram
HR	=	heart rate
HRmax	=	maximal heart rate
%HRmax	=	circulatory/cardiac strain
RPE	=	rating of perceived exertion
SCBA	=	self-contained breathing apparatus
$\dot{V}O_2$	=	oxygen consumption (absolute: l/min, relative: ml/min/kg)
$\dot{V}O_2max$	=	maximal oxygen consumption
$\%\dot{V}O_2max$	=	relative aerobic strain

1 INTRODUCTION

Fire departments in Finland represent an official state-wide rescue organization. Their action is based on the Act on Fire Fighting and Rescue Operations (Laki palo- ja pelastustoimesta 559/4.7.1975) and on the corresponding statute (Asetus palo- ja pelastustoimesta 1089/31.12.1975). Furthermore, the State issues decrees and recommendations. Municipalities can also organize their fire-fighting and rescue work according to various municipal laws.

In 1991 there were 1305 fire brigades in Finland. The number of municipal fire brigades was 856. Of these, 56 were full-time fire brigades, 184 were part-time fire brigades, and 616 worked on the contract basis. The rest were specialized industrial, military or airport fire brigades.

In 1991, the number of permanently employed fire service personnel (professional fire fighters) was 4667. Over half of these (2853) belonged to the operative staff. The number of side-line, task-paid and contract-paid fire service personnel was 15 176.

In Finland, municipal fire departments were called out 41 749 times to various fire-fighting and rescue operations in 1989. In addition, they received 204 558 calls for emergency ambulance service. About half (99 012) were emergency ambulance calls and 105 546 were non-emergency ambulance calls (Frelander, Ministry of Internal Affairs 1993, personal communication).

From 1987 to 1990 the mean annual injury frequency of professional operational fire fighters was 388 (causing at least three days' sick leave). The main events resulting in injuries were slipping and tripping, overstrain or an accident involving human motion, and stepping on objects or being struck by objects; the mean annual injury frequencies were 119, 90 and 67, respectively (Lindqvist-Virkamäki, unpublished results).

The fire-fighting and rescue tasks of the operative staff are diverse, and vary considerably in different municipalities. The following tasks are typical (Curriculum of the State Fire and Rescue Institute, 1993):

- preparation and clearing tasks
- extinguishing and rescue work, supporting activities and damage control
- boat and vessel transportation
- control room duties
- collaboration tasks (education and training, practice drills, physical exercise).

In many municipalities, emergency ambulance service is an essential part of the work.

Fire-fighting and rescue work requires a crew at all hours. In Finland, a 24-hour shift or a two-shift system is used most commonly. In the two-shift system, the length of the shift is 9 or 15 hours (Hakola et al. 1988).

In Finland fire fighters are educated and trained at the State Fire and Rescue Institute and at the Rescue Institute of the City of Helsinki. The basic training period lasts for 1.5-2 years. The first female fire-fighter student has recently started her training at the State Fire and Rescue Institute.

Good physical fitness is needed in the work of fire fighters, the police, ambulance personnel, correctional officers and military personnel. However, the precise quality and quantity of fitness required by these jobs has not been reliably defined and the available standards have not been validated against actual job demands (Shephard 1991).

Job seniority and/or unfitness of a worker may allow the choice of less demanding tasks or other workers may occasionally be persuaded to help disabled persons to accomplish the heaviest tasks (Shephard 1991). This type of flexibility is not always possible in fire-fighting and rescue operations, especially in smaller fire brigades. They have only few fire fighters on duty, and each one should be able to perform all the work tasks.

At the end of the decade about 40% of the workforce in the OECD (Organization for Economic Co-operation and Development) countries will be at the age of 45-65 years (WHO 1993). Also the mean age of Finnish professional fire fighters is rapidly increasing. This trend will be accentuated if the retirement age of fire fighters is raised from 55 to 65 years, as proposed. This is a challenge for the authorities and occupational health services, being responsible for the safety, health and work ability of fire fighters.

In the maintenance of fire fighters' work ability, the use for specific cardiorespiratory fitness tests in particular is warranted due to the age-related decline of the aerobic capacity. A combination of cardiorespiratory laboratory assessments and work simulation tasks might form the basis of a reasonable battery, useful in employment decisions (Sothmann et al. 1992a).

Throughout the occupational career physical work capacity is an important part of fire fighters' work ability, in addition to the psychological and social dimensions of work ability. Moreover, fire-fighting and rescue work requires a high level of occupational skills and knowledge. Physical work capacity can be divided into cardiorespiratory capacity, muscular performance, and motor coordination. The present series of studies has mainly concentrated on the cardiorespiratory capacity of fire fighters.

2 REVIEW OF THE LITERATURE

2.1 Theoretical framework

Several theoretical frameworks are available for the research of physiological aspects of professional fire-fighting and rescue work.

The stress-strain concept was primarily developed for heavy dynamic muscle work by Rutenfranz (1981 and 1985). The concept includes work stress factors and individual characteristics and abilities which determine strain on a worker (Figure 1). The work demands can exceed the capacities of the worker, thus inducing overstrain. If the work demands are lower than the worker's abilities and needs, understrain is induced (Ilmarinen et al. 1991b). The stress-strain relationships are greatly influenced by an individual's motivation, occupational skills and training (Rohmert 1982 and 1984).

In physical work, undesirable high or low strain, according to the stress-strain concept, can lead to harmful physiological responses, psychological reactions, and behavioural changes. In the long run, harmful strain can decrease functional capacity and work ability, and lead to disorders, and even work-related and occupational diseases. A harmonious relation between work demands and individual capacities promotes health and work ability regardless of age (Ilmarinen et al. 1991b).

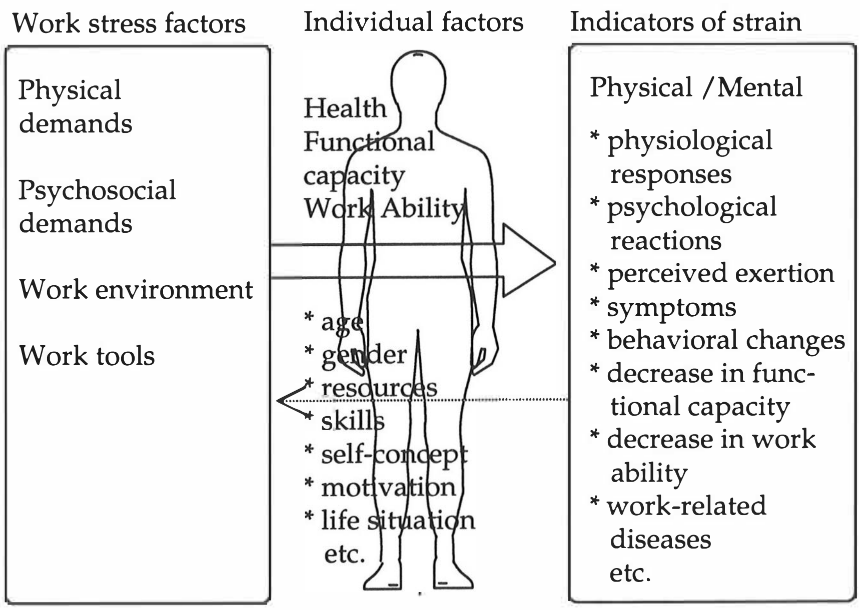

FIGURE 1 Stress-strain concept (Ilmarinen 1991b)

In dynamic physical work with large muscle groups, absolute $\dot{V}0_2$ (oxygen consumption) has been used as a determinant of stress, as well as $\dot{V}0_2$ related to body weight and HR (heart rate) as indicators of strain. Thus, the $\dot{V}0_2$max (maximal oxygen consumption) of the worker is an important individual characteristic which modifies strain involved in heavy physical tasks (Ilmarinen 1984 and 1992).

In order to better understand the work-related activity of the musculoskeletal system, Winkel and Westgaard (1992) have introduced an exposure-effect model. In the model "external exposure" describes those aspects of the work which are not affected by the worker (e.g. weight of tools or duration of work task). "Internal exposure" means the forces in the target tissues. Parameters describing "acute physiological and psychological responses" are e.g. changes in HR or perceived fatigue. "Cronic effects" may be either injuries or training effects. This model is also highly intervened by individual characteristics.

Armstrong et al. (1993) have developed a dose-response model to highlight the multifactorial nature of work-related neck and upper-limb disorders. The model can be characterized as the four levels of interacting variables: exposure, dose, capacity and response variables, so that the response at one level can act as the dose at the next level. External exposure (e.g. job demands) produce the internal dose (e.g. tissue loads and metabolic demands and factors). For example, the size, shape and weight of work objects are important determinants of tissue loads. Dose refers to those factors that disturb the internal state of the individual. Disturbances may be mechanical, physiological and/or psychological in nature. Assessment of muscle forces and joint position are probably most commonly used to evaluate the internal dose of the musculoskeletal system.

In the present study, the stress-strain concept was primarily used as a theoretical framework of research.

2.2 Stress in fire fighting and rescue work

2.2.1 Environmental stress factors

In emergency situations a fire fighter must act quickly and effectively. In a high-building fire, a fire fighter may have to climb stairs while wearing personal protective equipment and to carrying tools weighing up to 50 kg. After climbing, a fire fighter should be able to help a victim or to resist the propulsive force of a water spout. In rescue operations associated with traffic accidents, a fire fighter must often use hydraulic tools weighting 15-20 kg in strenuous working positions (Jaakkola 1984).

The most harmful health hazards in the work environment are due to ambient smoke consisting of explosive chemicals, toxic gases, solvents and dusts (Harinen & Honkonen 1980). Fire fighters are frequently exposed to carbon monoxide, hydrogen cyanide, nitrogen dioxide, sulphur dioxide, hydrogen chloride, aldehydes, and organic compounds such as benzene (Gold et al. 1978, Guidotti & Clough 1992, Treitman et al. 1980). Smoke is a variable mixture of compounds; its toxicity varies greatly, depending mainly on the type of fuel, the heat of the fire, and the amount of oxygen available for combustion (Guidotti & Clough 1992).

In a toxic atmosphere, a fire fighter must use an isolating respiratory protective device (Matticks et al. 1992). An SCBA (self-contained breathing apparatus) allows a fire fighter to enter and to work in a contaminated environment by maintaining positive pressure inside a full-face mask, which prevents toxic fumes from mixing with the inspired fresh air taken from a container.

Fire fighting takes place under a wide range of thermal conditions, because of variations in protective clothing, season and climate, geographic location, and the intensity of the heat in the fire situation (Matticks et al. 1992).

The risk for injury in fire-fighting and rescue work results mainly from the use of various heavy machines and apparatuses, dangerous entrances and awkward spaces for moving, extreme heat exposure, and rapidly changing thermal conditions (Harinen & Honkonen 1980). A fire fighter is also frequently exposed to high noise levels, which may include extreme peaks of impulsion (Matticks et al. 1992, Reischl et al. 1979, Tubbs 1985).

2.2.2 Physical job demands

Dynamic work stress or work demands can be objectively described with the measurement of absolute $\dot{V}O_2$ (l/min) during work. The energetic strain at a given level of absolute $\dot{V}O_2$ varies, however, depending on an individual's cardiorespiratory work capacity and body weight (Ilmarinen 1984). The cardiorespiratory strain varies also according to the individual's muscular performance, motor coordination and occupational skills.

Lemon and Hermiston (1977b) evaluated the $\dot{V}O_2$ requirements of four routine fire-suppression tasks, in which the fire fighters wore fire-protective equipment. The tasks included ladder climbing, rescuing a victim, dragging a hose, and raising a ladder in a thermoneutral environment. The average $\dot{V}O_2$ in the tasks was 2.39 l/min.

Louhevaara et al. (1985) reported the mean $\dot{V}O_2$ levels of 2.1-2.8 l/min in various fire-fighting tasks (range of ambient temperature: 2^oC to 120^oC) which lasted for 22-46 min. The fire fighters used a pressure-demand type of SCBA and fire-protective clothing, or an impermeable gas-protective suit.

Sothmann et al. (1990) used a portable $\dot{V}O_2$ monitor integrated with the SCBA for the measurement of $\dot{V}O_2$ while the fire fighters performed a simulated fire-suppression protocol wearing turnout gear. The average $\dot{V}O_2$ and working time were 2.5 l/min and 9 min, respectively. Sothmann et al. (1992b) also predicted a $\dot{V}O_2$ level of 2.28 l/min from the heart rate (HR) measured in actual emergency situations.

The personal protective equipment needed in fire-fighting and rescue work imposes considerable additional physical stress on the fire fighters. The extra weight and insulating properties of the equipment are the main factors which increase physical work stress, especially when the work is dynamically strenuous and carried out in the heat (Ilmarinen & Mäkinen 1992).

The SCBA and fire-protective clothing weigh about 25 kg. Each kilogram of extra weight within the range of 0-30 kg almost linearly increases pulmonary ventilation by 0.6 l/min (Borghols et al. 1978). In dynamic work loads in which the $\dot{V}O_2$ is higher than 50% of the maximum, however, the relationship between the weight carried and the pulmonary ventilation is no longer a linear one (Borghols et al. 1978). Energy expenditure per body is about equal when the weight is carried as an external weight or as additional body mass. Tönnes et al. (1986) found that the $\dot{V}O_2$ of fire fighters increased 1.15 l/min when an extra weight of 67 kg (consisting of breathing apparatus and two hose rolls) was carried by walking.

In the study of O'Connell et al. (1986) the $\dot{V}O_2$ of fire fighters who walked on a stair-treadmill averaged 1.78 l/min without fire-protective equipment. With the equipment the $\dot{V}O_2$ was 3.15 l/min and reached near maximal working levels.

Sköldström (1987) reported that the use of fire-protective equipment (turn-out gear and SCBA) increased $\dot{V}O_2$ by 0.4 l/min at a submaximal work level (20-30% of $\dot{V}O_2max$) at temperatures of 15°C and 45°C. The test lasted for 60 min. Duncan et al. (1979) observed a similar increase in $\dot{V}O_2$ at corresponding work levels. Louhevaara et al. (1984) found an 0.9 l/min increase in $\dot{V}O_2$ at a work level of about 60% of $\dot{V}O_2max$ and an 0.3 l/min increase during work at a level of about 30% of $\dot{V}O_2max$ in a thermoneutral environment.

Purswell et al. (1991) conducted a questionnaire survey which covered nine fire-fighting and rescue tasks, such as rescuing a victim, or forcible entry. In these muscularly demanding tasks, the average working times were less than two minutes. The rated frequency of the tasks was, on average, a few times per year. On the other hand, the tasks with the greatest perceived exertion were done several times a year by some respondents.

2.2.3 Psychological job demands

Fire-fighters are exposed to psychological stress induced by the situation, and to stress caused by their role as a help provider (Fullerton et al. 1992). Besides their personal safety, fire-fighters are responsible for the safety of others who are in danger usually in extreme situations. Fire-fighters sometimes witness events that produce pain, injuries, and strong emotions. The rescuing of helpless victims is one of the most stressful tasks; hearing that children are in a burning house was the highest ranked psychological stress factor reported by Boxer and Wild (1993).

Fire-fighters are usually highly trained in the technical aspects of fire and rescue work. They have a high social status, and are considered to belong to one of the blue-collar occupations having the highest skill qualifications (Kalimo et al. 1980). Fire-fighting and rescue work is considered stimulating and varying. The job offers an opportunity to interact socially, there is a high degree of autonomy between alarms, and a considerable number of free hours between work shifts. Fire-fighters have a strong team or group sense as its equal members (Guidotti 1992).

Shift and night work markedly emphasizes the effects of different environmental stress factors, e.g. noise, lighting and ambient temperature (Rutenfranz et al. 1985, Åkerstedt 1988 and 1990). Fire fighters may also experience considerable stress due to the intermittent nature of their work. Occasional and unpredictable emerge tasks occur between long work periods of full readiness for departure (Kalimo et al. 1980).

2.3 Individual characteristics of fire fighters

2.3.1 Health status

Health requirements and examinations

The evaluation of the health of fire fighters for duty should include a determination of their ability to adapt to the environmental and psychophysiological stress factors of the job. The cardiorespiratory health of fire fighters is particularly important. Smoking habits, hypertension, heredity and obesity have been shown to be reliable predictors of susceptibility to heart diseases in fire fighters (Davis & Dotson 1987). In addition to these factors, Adams et al. (1990) have reported risk factors for an ischemic heart disease including age and gender, physical inactivity, diabetes mellitus, diet, elevated blood lipids, personality type, behavior patterns, high uric-acid levels, pulmonary function abnormalities, ECG (electrocardiographic) abnormalities during rest and exercise, as well as tension and stress. The physician should examine these factors, and the medical history should be negative for ischemic heart disease. It would be prudent to screen fire fighters regularly for ischemic heart disease by means of a clinical exercise test. The test result should exceed the maximum and symptom-limited level, and no malignant ECG abnormalities should be noted. Moreover, the physician should determine body habitus, prior exercise history and presence of any orthopedic limitations, especially a prior history of musculoskeletal injury (Davis et al. 1982a, Matticks et al. 1992).

With regards to sensory functions fire fighters should not suffer from vertigo, should have unimpaired binocular vision, and adequate bilateral auditory perception in the speech range. All these are essential to proper balance, vision and communication (Davis et al. 1982a). Sensory functions are important in the prevention of injuries.

Health of fire fighters

The resting systolic and diastolic blood pressure of fire-fighters in the USA ranged from 137 to 142 and from 84 to 88 mmHg in fire fighters aged from 20 to 65 years, respectively (Byrd & Collins 1980, Saupe et al. 1991). Cady et al. (1985) found that 22% of the studied 1725 fire fighters had hypertension or borderline hypertension. Saupe et al. (1991) reported that borderline to moderate hypertension increased from 20% to 73% of fire fighters in different age groups (and mild to moderate pulmonary impairment from 10% to 53%, respectively). They also observed that fire fighters aged 20-65 years resembled the sedentary population of the same age with the respect to their cardiorespiratory health. According to Kilbom (1980) the resting systolic and diastolic blood pressure of 470 Swedish fire fighters ranged from 127 to 140 and from 76 to 86 mmHg, respectively, in age groups of 20 to 59 years. About every tenth (11%) of the fire fighters were unable to complete the clinical exercise test. The most common causes for interruptions were physical exhaustion, changes in ECG, high blood pressure, or joint pain.

Contradictory results concerning the elevated risk of fire fighters to have a fatal heart disease have been presented (Guidotti & Clough 1992). For example, Dibbs et al. (1982) and Rosénstock et al. (1990) reported that the mortality of fire fighters is close to that expected, whereas Sardinas et al. (1986) have proposed an elevated risk because standardized mortality odds ratio for their fire fighters was greater than 1.00. Although some additional risk of increased ischemic heart disease in fire fighters has been suggested, the specific role of occupational risk factors remains to be determined (Sardinas et al. 1986). In Finland, the prevalence rate for cardiovascular diseases among municipal fire fighters of over 45 years was 14% in 1981 and 21% in 1985; the incidence rate between the years 1981 and 1985 was 10% (Tuomi et al. 1991). The corresponding rates for other municipal workers of the same age were 21%, 28% and 14%, respectively.

The inhalation of smoke has well described acute negative respiratory effects (e.g. Musk et al. 1979, Unger et al. 1980). Chronic changes in pulmonary function and a relationship between occupational exposure and increased respiratory symptoms and diseases have been demonstrated by Peters et al. (1974), Rosénstock et al. (1990), Sparrow et al. (1982) and Unger et al. (1980). Some reports, however, indicate that long-term occupational exposure was not associated with pulmonary function abnormalities because of the increased use of protective respiratory devices and the selection of healthy and fit men for service (Horsfield et al. 1988, Loke et al. 1992, Musk et al. 1982, Tashkin et al. 1977).

The most common injuries associated with fire fighting are burns, falls and hits from falling objects (Guidotti & Clough 1992). Heineman et al. (1989) emphasize the importance of considering environmental and job demands over personal characteristics in the injury epidemiology, because the age and experience of fire fighters did not seem to be related to the frequency of injuries in service.

Limited attention has been paid to fire fighters' musculoskeletal disorders, although there is an increased risk for musculoskeletal injuries in fire-fighting and rescue tasks and during physical exercise sessions. In the USA, back injuries constitute a major cause of disability among fire fighters (Matticks 1992). This finding is in agreement with the results of Cady et al. (1985) who found that the most frequent complaints among fire fighters concerned problems with the back (12%), knees (6%), and other parts of the musculoskeletal system (11%). In Finland, the prevalence rate for musculoskeletal diseases of aging fire fighters was 39% both in 1981 and 1985; the incidence rate was 18 % between the years 1981 and 1985. The corresponding rates for other elderly municipal workers were 33%, 46% and 28%, respectively (Tuomi et al. 1991). It was also found that, on average, 20% of fire fighters aged 49 years had reduced work ability. The mean relative proportion of reduced work ability in other municipal workers of the same age was 15% (Tuomi et al. 1991).

The health status of fire fighters is relatively good in spite of their occasionally extreme job demands and exposure to safety hazards. Probably the entry into the occupation through selection criteria and adequate training guarantees a reasonably high health status throughout the career of fire fighters.

2.3.2 Anthropometrics

In the USA and in England the amount of mean body fat of male fire fighters ranged from 17.7% to 21.3% of body mass (Adams et al. 1986, Brown et al. 1982, Byrd & Collins 1980, Davis & Dotson 1987, Davis & Starck 1980, Hagan et al. 1991, Lemon & Hermiston 1977a). English fire fighters had significantly more fat than mine rescue brigades men and workers in the heavy industry in comparable age groups (Brown et al. 1982). Saupe et al. (1991) observed that the relative number of fire fighters with over 25% body fat, increased from 0% to 77% in the age groups from 20 to 65 years. In Canada, the body mass index of fire fighters varied from 24.9 to 28.0 kg/m^2 in the age groups from 20 to 59 years (Horowitz & Montgomery 1993).

Excessive body fat impairs mobility and heat dissipation, and increases the probability of orthopedic problems. Davis and Starck (1980) reported that the amount of body fat more than 20% had a more deleterious effect on physical performance than aging. They argue that the maintenance of appropriate body composition can enhance performance in the age groups of over 40 years by as much as 30%.

2.3.3 Physical work capacity

Cardiorespiratory demands

A maximal cardiorespiratory (aerobic) capacity, i.e. $\dot{V}O_2max$ of at least 2.8-3.0 l/min, has been considered necessary to guarantee an adequate safety margin in work situations encompassing heavy dynamic muscular work and exposure to severe heat (Zylberstein 1973). Also Louhevaara et al. (1985) confirmed the recommendation that a fire fighter wearing the SCBA should have a $\dot{V}O_2max$ of at least 3.0 l/min. Sothmann et al. (1990) proposed that a minimum $\dot{V}O_2max$ of 33.5 ml/min/kg was appropriate to maintain the performance effectiveness of fire fighters. Later Sothmann et al. (1992b) recommended a $\dot{V}O_2max$ ranging from 33.5 to 42.0 ml/min/kg for fire fighters. O'Connell et al. (1986) concluded that the $\dot{V}O_2max$ value of 2.7 l/min and 39.0 ml/min/kg was the minimum requirement for fire fighters to perform a fire-suppression task satisfactorily. Similar levels of $\dot{V}O_2max$ were recommended previously by Lemon and Hermiston (1977b). In Canada and in England, $\dot{V}O_2max$ of 45 ml/min/kg was recommended as the minimum standard for fire-fighter applicants (Gledhill & Jamnik 1992a, Horowitz & Montgomery 1993, Sykes 1991) (Table 1). In Germany, fire fighters are considered to be fit enough for work if they are able to exercise on a bicycle ergometer at a work load of 3 W per each kilogram of body weight (Griefahn, personal communication). $\dot{V}O_2max$ expressed in relation to body mass (ml/min/kg) and its absolute value (l/min) are both important because a fire fighter must be able to carry his/her individual body weight, as well as heavy external loads in actual work situations.

TABLE 1 Proposed minimum values for the $\dot{V}O_2max$ of fire fighters and fire-fighter applicants

$\dot{V}O_2max$ l/min	ml/min/kg	Reference
2.8-3.0		Zylberstein 1973
3.0		Louhevaara et al. 1985
	33.5	Sothmann et al. 1990
	33.5-42.0	Sothmann et al. 1990
2.7	39.0	O'Connell et al. 1986
	40.0	Lemon & Hermiston 1977b
	45.0[a]	Gledhill & Jamnik 1992a Horowitz & Montgomery 1993 Sykes 1991

[a] for applicants

Cardiorespiratory capacity

Studies on the physical fitness of fire fighters have fairly consistently shown that most fire fighters are as fit or somewhat fitter than the general adult male population (Guidotti 1992). When fire fighters were compared to sedentary male populations, they appeared to be superior in strength measurements, but did not differ significantly in the measurements of aerobic fitness (Davis et al. 1982a, Lemon & Hermiston 1977b).

Several studies in the USA and in Canada have focused on the $\dot{V}O_2max$ of fire fighters of different ages using relatively small sample sizes and different methods. The values of $\dot{V}O_2max$ have ranged from 34.7 to 42.3 ml/min/kg assessed by the maximal exercise tests of Adams et al. (1986), Davis et al. (1982b), Lemon and Hermiston (1977a), and Sothmann et al. (1990 and 1992b), and by the submaximal exercise test of Byrd and Collins (1980). Barnard et al. (1975), O'Connell et al. (1986), and Schonfeld et al. (1990) using maximal and submaximal exercise test protocols have reported higher average $\dot{V}O_2max$ values for fire fighters, ranging from 48.4 to 49.9 ml/min/kg. On the other hand, Horowitz & Montgomery (1993) examined 1303 fire fighters and found that fire fighters had a lower cardiorespiratory capacity than the average Canadian population of similar age. The lower endurance of the fire fighters was attributed to their additional body mass and elevated HR response to the submaximal step test, the reliability of which, however, can be critized.

Brown et al. (1982) reported that fire fighters in the U.K. had significantly lower $\dot{V}O_2max$ levels determined by a submaximal test protocol than those of mine rescue brigades men and workers of comparable age in the heavy industry. Kilbom (1980) reported that $\dot{V}O_2max$ of 399 Swedish fire fighters averaged about 40 ml/min/kg determined by a submaximal test protocol. Kukkonen and Rauramaa (1982) and Salorinne (1979) used a maximal test protocol, and Louhevaara et al. (1985) used a submaximal test protocol, and reported the $\dot{V}O_2max$ of Finnish fire fighters to range from 45.0 to 47.9 ml/min/kg with small and voluntary samples. Louhevaara and Lusa (1992) studied the $\dot{V}O_2max$ of 372 fire fighters based on submaximal bicycle exercise tests in the City of Helsinki. The average $\dot{V}O_2max$ of the fire fighters was 43.6 ml/min/kg. Finnish fire fighters were fitter than average Finnish men in all age groups from 20-29 to 50-59 years.

The interpretation of the results of studies of cardiorespiratory capacity of fire fighters is somewhat difficult because researchers have used different samples (number, age, training) and methods (e.g. maximal/submaximal test protocol, bicycle ergometer/treadmill). However, it seems that $\dot{V}O_2max$ of fire fighters in Finland and in Sweden is better than that in the USA, Canada and U.K. (Brown et al. 1982, Horowitz & Montgomery 1993, Kilbom 1980, Louhevaara & Lusa 1992, Sothmann et al. 1990).

Muscle and joint performance

Maximal isometric hand-grip strength, which is the most commonly used measurement of maximal muscle performance in fire fighters, varied between 44.0 to 64.0 kg in different studies (Brownlie et al. 1985, Byrd & Collins 1980, Davis & Starck 1980, Davis et al. 1982b, Hagan et al. 1991, Lemon & Hermiston 1977a, Schonfeld et al. 1990). Horowitz and Montgomery (1993) observed in their comprehensive study that fire fighters, when compared to the fitness norms of the average Canadian population, had better muscle strength and flexibility (measured by a sit-ups, push ups and sit and reach test). Generally, the muscle strength of fire fighters decreased with age (Lemon & Hermiston 1977a) as also with other individuals, but not so much as the $\dot{V}O_2max$. One exception was maximal isometric hand-grip strength, which was, on average, at about the same level in all age groups of studied fire fighters (Byrd & Collins 1980, Lemon & Hermiston 1977a). The content of the work and leisure time activities may provide such a strong stimuli which help to maintain the grip strength of fire fighters. Tulppo et al. (unpublished results) measured isokinetic muscle forces of 124 fire fighters (tests for the trunk, arms, legs and lifting) and found that the values remained almost unchanged until the age of 50 years. It is concluded, that the average musculoskeletal performance of professional fire fighters is considerably better than that of their sedentary counterparts.

Aging and physical work capacity

In cross-sectional studies the reported rate of decline in $\dot{V}O_2max$ with age for men varies from 0.20 to 0.52 ml/min/kg per year (Buskirk & Hodgson 1987). The age-related rate of decline for $\dot{V}O_2max$ of men reported in longitudinal studies varies from 0.23 to 1.04 ml/min/kg per year (Buskirk & Hodgson 1987). Sothmann et al. (1990) observed the mean $\dot{V}O_2max$ of the youngest fire fighters (20-25 years) to be 47.4 ml/min/kg, whereas the mean $\dot{V}O_2max$ of the oldest fire fighters (60-65 years) was 27.4 ml/min/kg. Kilbom (1980) reported that the age-induced decline in $\dot{V}O_2max$ was approximately 0.8 l/min from the age group of 20-29 years (3.7 l/min) to the age group of 40-49 years (2.9 l/min). The decline up to the age of 60 years was about 1.3 l/min. Byrd and Collins (1980) reported that the decline of the $\dot{V}O_2max$ of fire fighters with age was similar to the decline observed in the average population. In three age groups of 40-45, 50-55, and 60-65 years 73%, 67% and 97% of the fire fighters, respectively, remained below the 3 l/min recommendation for $\dot{V}O_2max$ (Saupe et al. 1991), and the decline of $\dot{V}O_2max$ was steeper than that in sedentary individuals after the age of 40 years.

Sothmann et al. (1990) reported that life-style rather than the consequences of aging per se causes the decline in $\dot{V}O_2max$ for fire fighters, because their recommended minimum level of aerobic fitness can be maintained well into the sixth decade of life of healthy individuals (Buskirk & Hodgson 1987). The decline of $\dot{V}O_2max$ is due to an age-related decline in the maximal HR, stroke volume and oxygen extraction (Sothmann et al. 1992a). One factor that determines oxygen utilization is the amount of active muscle mass. Thus, a decline in $\dot{V}O_2max$ is not only due to the age-related decline in central circulatory performance, but also to age-related differences in muscle mass or to the ability to shunt blood to the exercising muscles (Lakatta & Gerstenblith 1992).

Lakatta and Gerstenblith (1992) have reported that cardiac output can be maintained at high levels in aged but highly motivated individuals. Alterations in cardiac function are most likely to be manifestations of the interaction between physical deconditioning and cardiovascular disease. Buskirk and Hodgson (1987) suggested that the decline of $\dot{V}O_2max$ is curvilinear. Physically active persons decline slowly, as long as they maintain a fitness program. Sedentary persons decline at a rapid rate from 20 to 40 years, and then demonstrate a slower rate of change from 40 to 65 years. The 25% to 45% decline in $\dot{V}O_2max$

diminished to 20% with moderate physical activity (Åstrand et al. 1973) and to 10% to 15% in those engaged in long-term, high intensity programs (Kasch et al. 1985).

Saltin (1986) reported that the mean $\dot{V}O_2max$ was about 35 ml/min/kg in 40- to 50-year-old sedentary men, but by the age of 70 years it was reduced by 30% to the average value of about 25 ml/min/kg. Well-trained active men aged 50 years who had a $\dot{V}O_2max$ as high as 55 ml/min/kg had at the age of 70 years fallen only to 40-45 ml/min/kg, i.e., by 20-25%, although they showed about the same reduction of HRmax as aging sedentary subjects (Saltin 1986). If life-style include no physical training, the decline could be even 20-25% according to a 4-year follow-up study of municipal workers (Ilmarinen et al. 1991a).

With aging it is possible for fire fighters to maintain the recommended minimum level of $\dot{V}O_2max$. The main determinants for $\dot{V}O_2max$ and the decline of $\dot{V}O_2max$ with age are life style and diseases (Buskirk & Hodgson 1987, Lakatta & Gerstenblith 1992).

Muscle strength tends to be better preserved than aerobic power (Shephard 1987). Cross-sectional studies suggest that the deterioration of muscle strength begins around at the age of 45 years, with subsequent reduction of about 1.5% per year (Vandervoort & McComas 1986, Young 1989). Many authors report a loss of at least 18 to 20% of muscle strength by the age of 65 years. For example, in the study of Viitasalo et al. (1985) the decline in maximal isometric strength of different muscle groups from the youngest (mean age: 33 years) to the oldest (mean age: 73 years) cohort varied from 35% to 47% in one Finnish men population. A four-year follow-up study on municipal workers between the age of 51 and 55 years showed that the decline in maximal isometric trunk flexion strength was about 20% among men, and the decline was independent of the occupational demands (Nygård et al. 1991). The main reason for the reduction of muscle performance seems to be a selective loss of function in type II muscle fibers, leading to a lower maximal power, maximal force, and maximal velocity. However, many studies have demonstrated that the muscle strength of elderly individuals can be maintained or increased by physical training up to the age of 70 years (Aniansson & Gustafsson 1981, Frontera et al. 1988).

Improvement of the physical work capacity of fire fighters

The adequate physical fitness of fire fighters is an essential part of their work ability. The occasional physical peak stress in the work are not sufficient to sustain a fire fighter's fitness at a level needed in operative tasks sometimes involving extreme multifactorial stress (Lemon & Hermiston 1977b, Kuorinka & Korhonen 1981).

There have been particularly interest in effective on-the-job exercise programs for fire fighters with the hope that improved aerobic and muscular fitness would decrease their incidence of both injuries and ischemic heart disease (Faria & Faria 1991, Hagan et al. 1991, Puterbaugh & Lawyer 1983). Many of these physical conditioning programs have been uncontrolled, failed to demonstrate possible physiological benefits derived from the administered training protocols (Adams et al. 1986).

The improvement of fire fighters' $\dot{V}O_2max$ after physical training has varied from 5% to 33% (Adams et al. 1986, Bahrke 1982, Brown et al. 1982, Cady et al. 1985, Faria & Faria 1991, Pipes 1977, Puterbaugh & Lawyer 1983). Physical fitness other than aerobic capacity may also protect against coronary heart disease. The findings of Hagan et al. (1991) suggest that also anaerobic capacity and muscular strength and endurance may protect against heart disease among fire fighters, but the authors have not discussed about the mechanism by which the protection might occur.

The physical conditioning program for fire fighters proposed by Bahrke (1982), had financial benefits measured by number and cost of compensation claims, medical cost, cost of hours lost and costs due to accident and illness. In the study of Cady et al. (1979) the physical conditioning prevented fire fighters' back injuries. The 14-year program for promoting the health and physical fitness of fire fighters has brought a 25% decrease in compensation costs (Cady et al. 1985) by lowering back and total injury costs and by decreasing number of disabling injuries. Barnard and Anthony (1980) also reported that a fitness program had a major role in decreasing the number of fire fighters' injuries on duty.

In the study of Schonfeld et al. (1990) each performance predictor for work could be enhanced by exercise training. Previously Adams et al. (1986) had reported that after the physical conditioning program lasting 14 weeks, the performance times in job-related test drills (dummy rescue and hose pull-tower climb) decreased significantly. Almost all subjects felt that the fire department should have an exercise program, and that a regular exercise program would increase their work ability (96% and 94%, respectively).

In fire-fighting and rescue work, the musculoskeletal system of fire-fighters is under severe strain during handling of heavy loads (lifting, carrying, holding, pushing, etc.). Recently Genaidy et al. (1992) suggested that it is possible to increase the physical capacity of individuals engaged in manual materials handling by physical training. The key question is, however, can physical training significantly reduce the frequency and severity of musculoskeletal disorders common in jobs of manual materials handling?

Gavhed and Holmer (1989) and Pandolf (1979) suggested that individuals with high $\dot{V}O_2max$ have a marked advantage while working in the heat. In addition, physically fit persons tolerate shift work better than unfit persons (Härmä 1993, Härmä et al. 1988a and 1988b).

It is obvious that physical training improves physical work capacity, but there are still many open questions. How important part does physical work capacity have in work ability? How is it possible to maintain physical work capacity in practise, and should programs also include e.g. health promotion? Would the programs be voluntary or mandatory and employed on duty or only during off-hours? The crucial question is also often whether the benefits of a conditioning program outweigh the costs need to be addressed? Anyway, the work ability of aging fire fighters can not be maintained without regular physical training.

2.4 Strain on fire fighters

2.4.1 Cardiorespiratory responses

Cardiorespiratory responses caused by fire-fighting and rescue equipment

During a 5-min simulated stair climbing the mean HR with fire protective equipment was 95% of HRmax (maximal heart rate) of the subjects, and it was 24% higher than without the equipment (O'Connell et al. 1986). In the task, the mean $\dot{V}O_2$ was 80% of $\dot{V}O_2max$ with the equipment being 35% higher than that without the equipment. The wear of the full protective equipment has been observed to elevate the HR, on average, by about 25 beats/min during submaximal work at thermoneutral environment (Sköldström 1987, Smolander et al. 1984). The mean increase in HR at a temperature of 45^oC was up to 73 beats/min during submaximal work for 60 min. This was due to the internal and external thermal stress in addition to extra load while wearing heavy impermeable clothing and the SCBA (Sköldström 1987). In the experiments of fire protective clothing and the SCBA (weight: 25 kg) two fire fighters (N=12) were able to perform two consecutive test walks on a treadmill (speed 4.5 km/h, grade 2^o) at the ambient temperature of 50^oC with the radiant heat exposure of 1000 W/body m^2. The recovery period between the walks was 15-30 min, and the test was interrupted when HR exceeded 90% of HRmax (Ilmarinen et al., unpublished results).

In a non-competitive fire-fighting exercise drill, Manning and Griggs (1983) did not find differences in HR when the subjects used no SCBA, used the light SCBA or heavy SCBA. HR increased rapidly to 70-80% of maximum within the first minute and then plateaued at 90-100% of HRmax until the drill was completed. The exercising time of the drill varied greatly depending on the used equipment. The time was shortest without the SCBA. Obviously, in all settings HR reached near maximal or maximal levels due to high equipment-related work rate.

Onset reactions

Barnard and Duncan (1975) measured the HR responses of 35 fire fighters aged 23-42 years during a habitual 24-hour work shift. In almost all cases high HR (175-195 beats/min) was noted during the first 3 to 5 min of a fire. Romet and Frim (1987) reported a slight i.e. 10 to 15 beats/min increase in HR at the beginning of the simulated scenario. In both studies a victim rescue and evacuation was the physically most demanding activity. Kuorinka and Korhonen (1981) observed no elevated HR when their fire fighters were approaching to the place of fire or during alarms. The contradicting observations may be resulted in differences in fire-fighting practices, environmental conditions, selection for occupation or training background.

Cardiorespiratory responses in actual or simulated situations

The physiological responses of fire fighters and their dependence on maximal cardiorespiratory capacity have been studied in actual work situations by Sothmann et al. (1992b), and in simulated tasks by Louhevaara et al. (1985), Davis et al. (1982b) and O'Connell et al. (1986) (Table 2). The mean HR and $\dot{V}O_2$ of the fire fighters varied from 157 to 178 beats/min (88-95% of HRmax) and from 26 to 39 ml/min/kg (63-80% of $\dot{V}O_2max$), respectively. The most demanding fire-fighting operations (e.g. lifting and carrying of objects) required a mean $\dot{V}O_2$ of 42 ml/min/kg. Almost each demanding operation (90%) required a mean $\dot{V}O_2$ of 23 ml/min/kg. The $\dot{V}O_2$ values of 42 and 23 ml/min/kg averaged 85% and 50% of $\dot{V}O_2max$, respectively (Gledhill & Jamnik 1992a).

The physiological responses of fire fighters have also been studied during simulated repair and rescue tasks in a chemical plant. The male fire fighters used the SCBA and impermeable gas protective clothing. The mean HR was 146-148 beats/min for the tasks. The mean $\dot{V}O_2$ of 2.4

TABLE 2 Fire fighters' heart rate (HR), relative circulatory strain (%HRmax), oxygen consumption ($\dot{V}O2$) and relative aerobic strain (%$\dot{V}O2max$) in actual or simulated rescue situations. The values are means±SD and ranges in parenthesis.

Tasks and type of work	Fire-fighting equipment	N	Age (years)	HR (beats/min)	%HRmax (%)	$\dot{V}O2$ (l/min)	$\dot{V}O2$ (ml/min/kg)	%$\dot{V}O2max$ (%)	Reference
Search and rescue of a victim, use of pike pole and axe, carrying hoses, ladders, etc. in actual operations	Turnout gear and SCBA	10	32 ± 3 -	157 ± 8 -	88 ± 6 -	- -	25.6 ± 8.7 -	63 ± 14 -	Sothmann et al. 1992b
Use of pike pole and axe, climbing stairs, rescue of a victim, as in actual situations	Turnout gear and SCBA	20	32 ± 6 -	173 ± 9 (156 - 193)	- -	2.5 ± 0.5 (1.7 - 3.7)	30.5 ± 5.6 (23.5 - 49.3)	76 ± 8 (58 - 94)	Sothmann et al. 1990
Ladder extension, standpipe carry, hose pull, rescue of a victim, forcible entry as fast as possible	Turnout gear and SCBA	100	33 ± 8 (21 - 57)	169 ± 12 (125 - 190)	- -	- -	- -	- -	Davis & Dotson 1978 Davis et al. 1982b
Stair-climbing, 5 min, 60 steps per min	Turnout gear and SCBA	17	32 ± 7 (27 - 51)	178 ± 10 (162 - 194)	95 ± 4 (84 - 100)	3.1 ± 0.3 (2.7 - 3.6)	38.6 ± 2.8 (32.4 - 44.0)	80 ± 9 (63 - 97)	O'Connell et al. 1986
Smoke-diving with simulated fires aboard ship or repair and rescue tasks	Fire-protective clothing or impermeable gas protective clothing, with SCBA	8	- (32 - 38)	- (142 - 160)	- -	- (2.1 - 2.8)	- -	- (54 - 74)	Louhevaara et al. 1985

l/min based on consumption of air corresponded to 70% of the $\dot{V}O_2max$ of the subjects (Smolander et al. 1985).

Sothmann et al. (1991) discussed about the prediction of $\dot{V}O_2$ according to the working HR in fire suppression tasks including e.g. climbing stairs, entering into a 54°C smoke filled room, removing a 68 kg dummy, and performing pulls on a pike pole apparatus. The actual $\dot{V}O_2$ measured directly with an ambulatory device (Morgan Oxylog) was approximately 20% less than that predicted by using the HR-$\dot{V}O_2$ relationship determined on a treadmill. In this study, the $\dot{V}O_2$, %$\dot{V}O_2max$ (relative aerobic strain) and HR averaged 31 ml/min/kg, 73% and 176 beats/min, respectively. Cardiorespiratory strain correlated linearly to work rate.

In spite of many methodological differences and various protective equipment used in the studies it can be concluded that average cardiorespiratory strain of fire fighters is high with regular near maximal or maximal phases in fire-fighting and rescue operations. In situations where a fire fighter had to use protective equipment the strain depends on the weight and technical features of the SCBA, insulative properties of protective clothing, muscular demands at work and a fire fighter's individual characteristics (Louhevaara 1986).

2.4.2 Thermal responses

In order to maintain body temperature in a hot environment, heat dissipation is accomplished by sweating, increased blood flow and peripheral vasodilatation; heat loss is thus increased through evaporation, radiation, and convection (Enander & Hygge 1990).

Clothing alters the rate and amount of heat exchange between the skin and the ambient air. Increasing the number of the water-vapor impermeable layers increases the evaporative heat exchange. This effect may also be coupled with significant additional heat stress, especially in environments with high relative humidity. When the skin temperature is below the ambient temperature, the only mechanism to dissipate heat in impermeable clothing is dry heat exchange by convection, conduction and radiation, although some heat exchange takes place through respiration (Ilmarinen 1978). The skin surface temperature, core temperature, and amount of sweat, in addition to HR, offer a good basis for controlling heat strain. A marked increase in these values during work is a sign of overstrain in the heat control system of the body (Hower & Blehm 1990). The risk of heat-induced physical exhaustion and heat stroke grows when the rectal temperature rises above 39°C (Hales & Richards 1987, Wenzel & Piekarski 1980).

The skin temperatures of fire fighters wearing personal protective equipment have been measured during simulated fire-fighting tasks by Romet and Frimm (1987), in laboratory conditions at a submaximal work level in a thermoneutral environment by White and Hodous (1987), and at a temperature of 45^{o}C by Sköldström (1987). The obtained skin temperatures in the above mentioned studies were 38.0^{o}C (highest), 36.7^{o}C (highest), and 38.2^{o}C (mean), respectively.

The highest rectal temperatures measured in a simulated fire-fighting tasks in the heat has been 40.2^{o}C (Ilmarinen, unpublished results) and 38.8^{o}C (Romet & Frim 1987), and in a thermoneutral laboratory environment 37.9^{o}C (White & Hodous 1987). The increase in rectal temperature was 1.3^{o}C in a building search and victim rescue task (Romet & Frim 1987), and 1.9^{o}C per hour in the laboratory (White & Hodous 1987). The increase of the core temperature continues for 10-20 min during a recovery period in a thermoneutral environment.

The mean weight loss of subjects was 1.17 kg in the laboratory after exercising with fire-protective equipment (White & Hodous 1987). The mean sweat rate in the laboratory at 39^{o}C was 811 $g/m^2/h$ (Faff & Tutak 1989) and at 45^{o}C it was 674 g/h (water was trapped in the clothes) (Sköldström 1987).

2.4.3 Local and subjective strain and fatigue

According to Tönnes et al. (1986) the fire fighters' main reason for interrupting the carrying of two hose rolls with full protective equipment (total extra weight: 67 kg) was the tiredness of the finger flexor muscles shown by a 60% increase in EMG (electromyography) amplitude compared to the initial level. In their biomechanical analysis of a task in which two subjects were carrying a victim without a stretcher, the greatest torque was at the vertebral disc of L5/S1 of the subject who was carrying behind. In the analysis of the calculated distribution of static loads on bearers who are standing still, the demands were observed to be high on the shoulder and back muscles (34% and 41% of maximal voluntary contraction, respectively) (Tönnes et al. 1987).

Fire fighters who had recently worked as paramedics or at the alarm center experienced more strain than the regular fire fighters (Dutton et al. 1978, Kalimo et al. 1980). About half of the fire fighters considered both the mental and physical load of their work as average (Kalimo et al. 1980). At the end of a work shift 42% of the fire fighters felt quite tired. The reasons given for subjective strain were busy work pace, physically heavy work, poor work postures, and continuous alertness. When all aspects of the occupation were evaluated, intermittent sleep was rated as the most severe cause of strain, and it was the factor that correlated most to fatigue.

After actual rescue work, the physical strain was described as great by 55% of the fire fighters. Age did not seem to be related to the experienced strain. Smoke-diving and rescue work were reported as composite stressful situations (Hytten & Hasle 1989).

The overall RPE (rating of perceived exertion) for the cardiorespiratory system in performing nine fire-fighting tasks requiring strength was most often considered fairly heavy (among 32-47% of the subjects). The controlling of an active hose line while putting off a fire was rated as heavy or very heavy by two of three subjects (67%). Almost half of the subjects (47%) rated rescuing a victim heavy or very heavy (Purswell et al. 1991).

RPEs have been studied in the use of different fire-fighting ensembles under laboratory conditions with fire-fighting ensembles. Subjects reported higher overall, leg and chest RPE during low intensity work (30% of $\dot{V}O_2max$) compared to RPEs during high intensity work (60% of $\dot{V}O_2max$) in the study of White et al. (1989). The overall RPE with three different fire-fighting ensembles varied from 16 to 17, and with a control ensemble it was 14. The mean RPE for the legs was 15 and for the chest 14. The data of perceived responses was correlated to the physiological load and strain, and indicated that the responses were influenced primarily by the type of ensemble and duration (not intensity) of the work. These data were supported by the observations of Shimozaki et al. (1988). They concluded that subjects were able to perceive their level of exertion accurately under laboratory conditions.

Sköldström (1987) reported that at the ambient temperature of 15^{o}C RPE increased throughout the work period, and finally reached the value of somewhat higher than would be predicted from the increase in HR. In a cool environment the RPE values probably reflected the exertion perceived in local muscle groups rather than overall fatigue due to exertion, since most complaints referred to problems in the shoulders and in the lower back. At the temperature of 45^{o}C the correlation between RPE and HR during the last minute of exercise was very high, and the mean thermal sensation was rated as very very hot by the subjects. This study suggests that fire fighters can well estimate the amount of their physiological and thermal strain under standardized laboratory conditions.

2.5 Assessment of the physical work capacity of fire fighters

2.5.1 Laboratory and field tests

Field tests can be done quickly without the use of complicated equipment and highly trained staff, whereas the situation in laboratory assessments is usually the opposite. The most commonly used laboratory methods for measuring the $\dot{V}O_2max$ of fire fighters have been a submaximal bicycle ergometer test, used especially for older fire fighters (e.g. Byrd & Collins 1980, Lemon & Hermiston 1977a) or a maximal bicycle ergometer test (e.g. O'Connell et al. 1986). In addition, many researchers have employed maximal treadmill tests with various protocols (Adams et al. 1986, Davis et al. 1982a, Lemon & Hermiston 1977a, Schonfeld et al. 1990, Sothmann et al. 1990). The criteria for $\dot{V}O_2max$ have varied in different studies, and according to Sothmann et al. (1990) a large number of subjects, especially older ones, have not achieved the generally accepted criteria for $\dot{V}O_2max$. Fire-fighting and rescue work includes frequent stair climbing or the use of ladders, therefore some researchers (e.g. Horowitz & Montgomery 1993) have used also the step-test for assessing fire fighters' cardiorespiratory capacity.

The direct assessment of $\dot{V}O_2max$ is one of the best standardised laboratory measurements. In spite of this the differences in the determinations on any given day can be few percentages (Wright et al. 1978). Fluctuation of 15% to 20% within a short period of time can occur if a subject's physical capacity is impaired by an acute illness. The medical evaluation before the test is necessary to prevent biased results and to minimize health hazards in the test. Other performance tests have a good face validity, but there is much evidence to show that their reliability is lower than that of $\dot{V}O_2max$.

The minimum requirement of 3.0 l/min (Kilbom 1980, Zylberstein 1973) for $\dot{V}O_2max$ means that fire fighters performing smoke-diving should be able to pedal on a bicycle-ergometer for at least six minutes at a work load of 200 W. According to the recommendations given to the pre-employment examinations, a fire-fighter applicant should be able to exercise for six minutes at a work load of 250 W (Kilbom 1980). These tests are carried out without protective equipment.

Fire fighters have been studied with numerous muscle strength and endurance and flexibility tests. The most common test has been a maximal isometric hand-grip strength test with different types of dynamometers (Brownlie et al. 1985, Byrd & Collins 1980, Davis & Starck

1980, Davis et al. 1982b, Hagan et al. 1991, Lemon & Hermiston 1977a, Schonfeld et al. 1990). The other common tests have been sit-up, push-up and sit-and-reach, which evaluate dynamic muscle endurance and strength, and trunk flexibility (Brownlie et al. 1985, Davis & Starck 1980, Davis et al. 1982b, Hagan et al. 1990, Pipes 1977, Schonfeld et al. 1990). Also isokinetic muscle tests have been employed in some studies (e.g. Adams et al. 1986, Schonfeld et al. 1990).

Gavhed and Holmer (1989) have suggested that the tolerance of fire fighters to exhausting work under heat stress cannot be predicted by tests of physical work capacity. A heat tolerance test would add valuable information in this respect. Shvartz et al. (1977) concluded that either physical fitness or HR responses to heat exposure could not accurately predict heat tolerance. Kenney et al. (1986) have recommended a exercise test for the prediction of heat tolerance. The test can be performed in an office environment with simple equipment by, for instance, a personnel of occupational health services.

2.5.2 Simulated test drills

The most common fire-fighting tasks simulated in drills are stair climbing, rescue of a victim, forcible entry (e.g. by striking) and working with ladders (Davis & Dotson 1978, Davis et al. 1982b, Gledhill & Jamnik 1992b, Lemon & Hermiston 1977b, Misner et al. 1987 & 1989, Schonfeld et al. 1990, Sothmann et al. 1990). In most of these test drills the subjects were asked to work as fast as possible, and the main outcome variable was the performance time. The test drills are summarized in Table 3 and previously in Table 2.

TABLE 3 Type of work, task, performance time and heart rate (HR) during job-related test drills

Type of work	Task	Performance time (s) $\bar{x}$	HR (beats/min) $\bar{x}$	Reference
Constant, predetermined work rate using fire-fighting equipment; expired gas volumes were collected	Aerial ladder climb	100	157	Lemon & Hermiston 1977b
	Rescue of a victim	32	134	
	Hose drag	30	139	
	Ladder raise	31	115	
As fast as possible or until exhaustion, adequate rest periods were allowed between the tasks, subjects wore sportswear	Stair climbing	13		Misner 1987, 1989
	Hose coupling	28		
	Flexed arm hang	65		
	Lift and carry	17		
	Modified stair climb	14		
	Ladder lift	8		
	Forcible entry	9		
	Dummy drag	9		
	Obstacle run	84		
Safely, quickly and efficiently without interruption, using turnout gear and SCBA	Stair climbing	127	173[a]	Schonfeld et al. 1990
	Chopping	69	175[a]	
	Rescue of a victim	57	179[a]	
As fast as possible, using turnout gear and SCBA	Rope pull	50		Gledhill & Jamnik 1992b
	Hose drag	27		
	Hose carry/climb	115		
	Rescue of a victim	27		

[a] 93-97 %HRmax (circulatory/cardiac strain)

The test-retest reliability of simulated test drills ranged from moderate to high (r=0.72-0.95) in the study of Misner et al. (1987) with two exceptions; hose coupling (r=0.37) and ladder lift (r=0.58). High test-retest reliability was found for two different stair-climbing tests (r=0.88 and r=0.95). Systematically, a significant improvement occurred in each test on the second test day. Higher reliability coefficients were found for women, although the largest absolute differences in test performance scores were observed in the female group. Women scored lower than men on occupationally related physical performance tests because they had less experience, were smaller in stature, and had less lean body weight than men (Misner et al. 1987).

Job-related test drills used for fire-fighting applicants (Misner et al. 1989) appeared to be reliable but highly specific, because the test drills correlated weakly to traditional muscular performance tests. Also Sothmann et al. (1990) reported high test-retest reliability for tasks in the test drill (r=0.75-0.93).

The subjects in the study of Sothmann et al. (1990) were asked to rate the reasonableness of the fire-suppression protocol by a scale from 1 (unreasonable) to 10 (very reasonable). The average rating was 8, indicating that the subjects considered the face validity of the protocol fairly good.

Simulated test drills have usually high reliability but they are task-specific. Commonly test drills were performed as fast as possible although that is not the case in actual operations. It should be better to perform the tests at habitual safe work rate without competing.

Predictors for physical performance

Excessive body fat (over 20%) has been shown to place a considerable additional load on the cardiorespiratory and musculoskeletal system during test drills (Davis & Dotson 1978, Davis et al. 1982b and Schonfeld et al. 1990). Misner et al. (1987) reported that the obesity markedly hampered performance in which the body was moved either vertically or horizontally. Large amount of active muscle mass, however, helps to improve performance particularly in physical tasks requiring much absolute force, such as lifting, and carrying of heavy loads or striking with heavy tools.

The study of Davis and Dotson (1978) demonstrated that age, $\dot{V}O_2max$ and maximal achievable HR in the laboratory were main predictors for an exceptionally good performance in the test drill. Sothmann et al. (1990) determined the minimal standard of aerobic fitness during performance of a simulated fire-suppression protocol, and found that the subjects in different age groups (21-26-, 31-36-, 41-50 years old), who all had a $\dot{V}O_2max$ above 33 ml/min/kg, had different performance times (7.5, 9.4 and 11.2 min, respectively). The performance times were nevertheless within the expectation time of 13.1 min. The subjects in different age groups had been also matched for height and body weight. In the study of Schonfeld et al. (1990) age was not a significant predictor of performance for any of the three simulated fire-fighting tasks in healthy males aged from 27 to 60 years.

Davis et al. (1982b) identified a "physical work capacity factor" and "a resistance to fatigue factor". These correlated highly to fire-fighting ability in experienced and trained fire fighters. Laboratory tests included in these factors (last treadmill grade, oxygen pulse, and HR) associated with field type of tests, such as push-ups, sit-ups and chin-ups, proved to be the best indicators of successful performance in job-related tasks. The treadmill endurance time, $\dot{V}0_2max$, peak torque during knee flexion and amount of body fat significantly correlated to the total performance time of three different fire-fighting tasks (Schonfeld et al. 1990).

In the study of Sothmann et al. (1990) $\dot{V}0_2$ was found to be somewhat below the anaerobic threshold during a fire-suppression protocol. Further lowering of the recommended minimum occupational level of $\dot{V}0_2max$ (33.5 ml/min/kg) would have increased the relative aerobic strain (%$\dot{V}0_2max$) to near anaerobic level at the same rate of work, or decreased work output in a given time: both are undesirable outcomes limiting the efficiency of work.

Misner et al. (1989) examined whether job-related tests were related to traditional physical performance tests. The correlations were low in general. The standing jump-test had the highest correlation to the job-related tests. Thus, leg power seem to be an important factor for successful performance in job-related tests. In most cases the tasks including the job-related tests involve more complex and skill-demanding movements than the traditional fitness tests.

Doolittle and Kayala (1987) performed kinesiological analyses of physically demanding, fire-fighting tasks by determining their typical anatomic movements and their biomechanical requirements. After these analyses and the estimation of the mass to be handled in the job, they recommended a test battery for fire fighters. Military press and biceps curl (27.5 kg, 19 minimum repetitions in both) tests corresponded to the ladder-raising task. Squat or leg press (54 kg plus body weight, 20 minimum repetitions in both) tests corresponded to a task encompassing standing after shoulder loading hose. The modified lateral pull (34 kg, 30 minimum repetitions) test corresponded to the extending fly and sailing pulling tasks. A step or stairmill test was recommended for assessing the aerobic power of fire fighters.

Many researchers have been interested in the predictors for stair-climbing work commonly done by fire fighters in actual situations (Ben-Ezra & Verstraete 1988, O'Connell et al. 1986). O'Connell et al. (1986)

concluded that stair climbing with fire-fighting equipment required the $\dot{V}O_2$ of at least 2.7 l/min (39 ml/min/kg).

Age is rarely a limiting factor to fire-fighting performance concluded by many researchers (e.g. Schonfeld et al. 1990). Body fat over 20% has more deleterious effect on physical performance than age. Maximal oxygen consumption appeared to be the best predictor for performance in simulated test drills.

2.6 Summary of the literature

Fire-fighting and rescue work is occasionally psychophysiologically extremely demanding, and exposure to extreme environmental conditions is common. Shift work enhances the negative aspects of fire fighting and rescue work.

A fire fighter needs to be healthy for the job, and to have good physical, psychological and social work ability, as well as occupational skills. Physically his/her cardiorespiratory and musculoskeletal fitness must be better than that of average Finnish middle-aged men, i.e. $\dot{V}O_2max$, for instance, should exceed 3.0 l/min or about 38-40 ml/min/kg. The maintenance of sufficient work ability requires regular physical exercise and training of occupational skills.

The results obtained in actual and simulated fire-fighting and rescue tasks show that both physiological and psychological strain may frequently reach near maximal or maximal levels. This is affected by the exposure to combined stress factors: strenuous dynamic work, use of heavy personal protective equipment, high work rate, a hostile and often hot environment, occasional and sudden peak loads and shift work. Extreme physiological strain occurs most commonly in tasks where the SCBA and protective clothing (fire protective or impermeable chemical suit) are needed in the heat.

According to Shephard (1987) a valid assessment of aerobic fatigue should be derived from observations made over the course of the working day, when possible (e.g., increments of HR, blood lactate and serum enzymes). Several investigators (e.g. Davis & Dotson 1987) have pointed out the need to evaluate also speed, strength and flexibility in public-safety-related occupations; such items are considered important to both job success and the prevention of injuries.

The ideal tests are reliable and valid in relation to frequently encountered job demands. They identify individuals who have the greatest probability of success in their work, and eliminate those most prone to overstrain and injury (Shephard 1991).

Prior to developing a job-related test, a careful job analysis should be done. The tests should be safe, reliable, valid and not too complex to perform. A combination of laboratory assessments and work simulations might form the basis of a reliable and feasible test battery for assessing the physical work capacity of fire fighters.

3 THEORETICAL FRAMEWORK OF THE STUDY

In this study the stress-strain concept was applied to fire-fighting and rescue work. The main variables of the study are presented in Figure 2.

In addition to the stress-strain concept, the present research project of five studies proceeded according to the approach of Chahal et al. (1992) while developing physical fitness tests for fire fighters. The five steps of the approach were the following:

1) Identification of the most physically demanding fire-fighting and rescue tasks and their frequency.
2) Identification and quantification of physical load and strain of the fire-fighting and rescue tasks rated as the most demanding.
3) Development and selection of appropriate and feasible tests which predict the ability of the fire fighters to perform the physically most demanding tasks.
4) The determination of population performance characteristics on the selected tests and the predictive relationships between the tests and performance in actual fire-fighting and rescue operations.
5) The determination of acceptable quantitative criteria for tests to assure that the fire fighters are able to complete the most demanding tasks.

This study concentrated mainly on the first three steps.

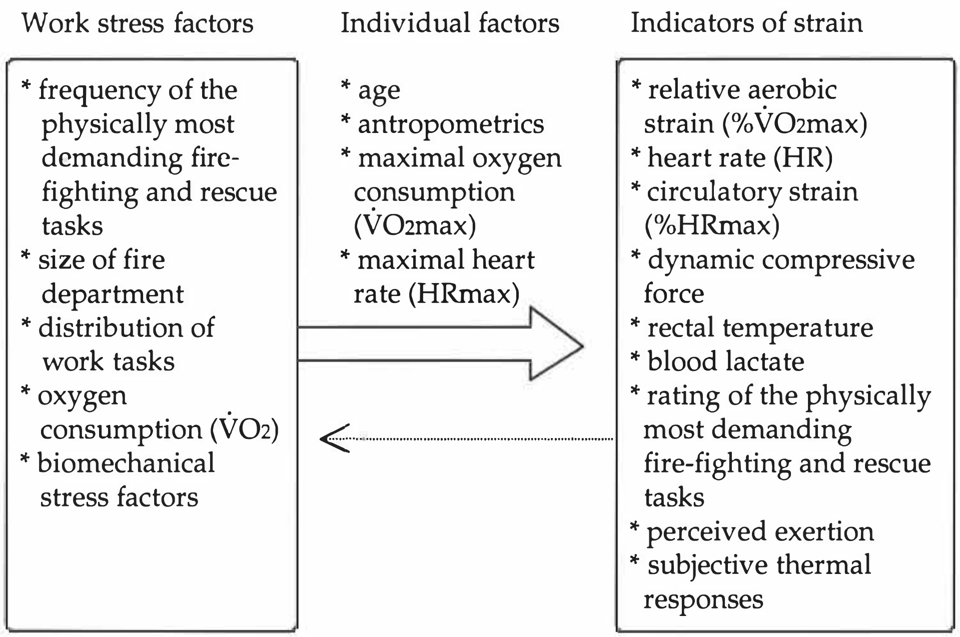

FIGURE 2 The framework of the study (adopted stress-strain concept) and the main variables of the study

4 PURPOSE OF THE STUDY

The purpose of the present study was to analyze physical job demands of fire-fighting and rescue work, and to develop and evaluate procedures for the assessment of fire fighters' cardiorespiratory work capacity in order to enhance their health, work ability and safety at work.

Specifically the following questions were posed:

1) Which fire-fighting and rescue tasks are rated physically as most demanding, what is the frequency of the tasks, and what are the effects of the age of fire fighters and the size of the fire department on the rating of the demands and on the frequency of the tasks? (Study I)

2) What is the distribution of the work tasks, and what is the proportion of fire fighters specialized in specific tasks at the fire departments? (Study I)

3) What are the physiological stress and strain (mean pulmonary ventilation, estimated mean oxygen consumption, average and peak heart rate, relative aerobic and circulatory strain) during simulated smoke-diving in the heat? (Study II)

4) What are the biomechanical stress factors (joint angles, speed of movement, and peak torques) and dynamic compressive force in the low back in older and younger fire fighters in simulated clearing task? (Study III)

5) What are the effects of fire-protective equipment on oxygen consumption, heart rate, relative aerobic and circulatory strain, rectal temperature and blood lactate as well as perceived exertion (overall rating of perceived exertion on the cardiorespiratory system and local rating on the legs) and on subjective thermal responses (thermal sensation and comfort) during a job-related exercise protocol on a treadmill developed for the assessment of cardiorespiratory capacity of fire fighters performing smoke-diving? (Study IV)

6) What are the estimated aerobic stress (absolute oxygen consumption), cardiac strain (heart rate and relative circulatory strain), and relative aerobic strain (oxygen consumption related to body mass and maximal oxygen consumption) imposed by the test drill developed for the worksite assessment of cardiorespiratory capacity of fire fighters, and what is the relationship between cardiac strain and maximal oxygen consumption and the age of fire fighters? (Study V)

5 MATERIAL AND METHODS

5.1 Subjects

In Study I the stratified sample of the questionnaire study encompassed 234 professional fire fighters who were on duty in all the 58 emergency areas of Finland. From each area the largest fire department and randomly another department were chosen for the study so that the total number of fire departments was 116. The number of fire fighters who received the questionnaire varied from 3 to 35 in each fire department, and included at best 10% of the permanent operational staff of the department. The 156 professional fire fighters (67% of the sample) responded to the questionnaire. Their mean (±SD) age was 36 (±8) years, ranging from 22 to 54 years.

In Study II the subjects were 35 healthy, young male fire-fighting students from the State Fire and Rescue Institute.

The subjects of Study III consisted of 6 aging and 7 young experienced fire fighters from the Fire and Rescue Department of the City of Oulu.

The subjects of Study IV were 12 and in Study V 59 healthy, experienced fire fighters. The subjects in Study IV were from the Rescue Department of the City of Helsinki, and in Study V from the Fire and

Rescue Department of the City of Oulu. The physical characteristics of the subjects are summarized in Table 4.

TABLE 4 Physical characteristics and maximal oxygen consumption ($\dot{V}O_2max$) and maximal heart rate (HRmax) of the subjects; values are means±SD

Paper	N	Age (years)	Height (cm)	Weight (kg)	Body fat (%)	$\dot{V}O_2max$ (l/min)	$\dot{V}O_2max$ (ml/min/kg)	HRmax (beats/min)
I	156	36 ±8	-	-	-	-		-
II	35	23 ±2	179 ±6	78 ±8	15[a] ±3	4.08 ±0.45	52.4 ±5.2	191 ±8
III								
Older	6	47 ±5	175 ±3	83 ±8	19[b] ±2	-	-	-
Younger	7	32 ±2	179 ±4	82 ±7	17[b] ±2	-	-	-
IV	12	34 ±5	182 ±7	82 ±12	-	4.1 ±0.4	51 ±6	195 ±11
V	59	39 ±7	177 ±6	83 ±11	-	3.82 ±0.59	46.8 ±9.1	184 ±13

[a]according to Durnin and Womersley (1974)
[b]according to Durnin and Rahaman (1967)

5.2 Methods

5.2.1 Maximal physical capacity (II-V)

Maximal oxygen consumption (II, IV, V)

The $\dot{V}O_2max$ of the subjects was measured directly using an incremental, multistage exercise test on an electric bicycle-ergometer (Tunturi EL-400, Tunturi Oy, Finland) (II, V) or on a treadmill (Juoksumatto, Telineyhtymä Oy, Finland) (IV).

In Study II the work load in the bicycle-ergometer test was increased by 50 W every 4th minute and in Study V by 25 W every second minute until exhaustion. In Study IV the subjects first walked on the treadmill for 5 min with 0^{o} inclination at a speed of 4.5 km/h. The speed was kept constant and every second minute the inclination was increased by 2^{o}. After the final inclination of 10^{o} the speed was increased by 0.5 km/h every second minute until exhaustion of the subject.

In Studies II, IV and V, expired air was directed through a low-resistance breathing valve, (small-dead-space Koegel "Y" breathing valve, Ewald Koegel Co., USA) (Lenox & Koegel 1974) and widepore tubing to a respiratory gas analyzing system (Medikro 202 Ergospirometer, Medikro Co., Finland), which calculated pulmonary ventilation, oxygen consumption, the production of carbon dioxide and the respiratory exchange ratio every 30 s. The gas analyzers were calibrated before each test with gas mixtures of known concentrations of oxygen and carbon dioxide. During the tests, an ECG was continuously monitored (OLLI 431D, Kone, Finland) and HR was registered every minute (II) or every 15 s (V) with the Sport Tester PE 3000 system (Polar Electro Oy, Finland). The following criteria for maximality were used: respiratory gas exchange ratio ≥ 1.00 and/or plateau of $\dot{V}O_2$ (II, IV, V).

Maximal muscle performance (III)

The isokinetic peak and average peak torques of the subjects were measured during back (standing position) and knee extension (sitting position) with the Lido Multi-Joint System (Loredan, USA) using the 180^{o}/s speed for the back extension and 240^{o}/s for the knee extension (Delitto et al. 1991, McCrory et al. 1989). The subjects also performed a sit-up test (maximal repetitions within 60 s) (Mälkiä 1983, Pollock & Willmore 1990) and a pull-up test (maximal repetitions) using conventional standardized test protocols.

5.2.2 Stress and strain

5.2.2.1 Characteristics of physically demanding work tasks (I)

The characteristics of physically demanding fire-fighting and rescue tasks were studied by a questionnaire. The questionnaire was prepared and tested in collaboration with the State Fire and Rescue Institute. The following information was collected:

A) Individual and occupational characteristics
level of education and training, period of service, number of citizens in a township served by a fire department, distribution of work tasks among the staff, amount of task-oriented specialization of the staff, and the main reasons for possible specialization.

B) Job demands on physical work ability
The fire fighters were asked to rate five operational fire-fighting and rescue tasks which were the most demanding on physical work ability in terms of aerobic power, muscular performance, and motor coordination, according to their own experience. The fire fighters were given a reference list of fire-fighting and rescue tasks used at the State Fire and Rescue Institute. They were also allowed to rate other tasks, which they felt to be among the five physically most demanding tasks in some of the three dimensions of physical work capacity.

C) Frequency of the tasks
The fire fighters were asked to estimate the average frequency of the rated fire-fighting and rescue tasks they had done during the last five years with the following scale: 1) at least once a month, 2) once in a period of three months, 3) once in a period of six months, 4) once a year, 5) once in a period of three years.

5.2.2.2 Cardiorespiratory stress and strain (II, IV, V)

For determining cardiorespiratory stress and strain the subjects performed smoke-diving (entry into a smoke-filled room and rescue of a victim) during a simulated shipboard fire (Study II). The smoke-diving was carried out in pairs, and during the task the subjects wore an SCBA and fire-protective clothing. Oxygen consumption was estimated from the volume of pulmonary ventilation calculated according to the decrease in the air container pressures. In the estimation, one l/min of $\dot{V}O_2$ corresponded to 22.5 l/min in the volume of pulmonary ventilation (Cotes 1979, Louhevaara et al. 1984, Smolander et al. 1985). During the entire smoke-diving, HR was registered every minute with the Sport-Tester PE 3000 system (Polar Electro Oy, Finland).

Fingertip blood samples were taken and analyzed for blood lactate in Study IV (YSI 23L, Yellow Spings Instruments, USA) (Graham & Andrew 1973).

Assessment of cardiac strain in the drill (V)

The job-related test drill was developed for smoke-diving in Study V. The submaximal test drill consisted of five common tasks associated with smoke-diving. They were done wearing full personal protective equipment. The tasks and their order were the following:

1) walking without and with two rolls of hose
2) climbing and ascending stairs
3) hammering a truck tire

4) going over and under bars
5) hose rolling.

A fixed maximal working time of 14.5 min was allowed for the drill. The fixed times for the tasks were four, three and a half, two, three, and two minutes, respectively. The HR of the subjects was monitored during the drill with a Sport-Tester PE 3000 (Polar Electro Oy, Finland) at the intervals of 15 s.

5.2.2.3 Biomechanical features (III)

The biomechanical evaluation of the simulated clearing task was done with the two-dimensional Lido Kinetic Analysis System (Loredan, USA). The task was evaluated in a sagittal line by identification of the markers of the joints according to a biomechanical model developed by Freivalds et al. (1984). The used computer-based video system estimated the movement speed and peak torque for the knee and back extension in the task. The angles of the hip and knee joints were measured at the beginning of the task. The maximal dynamic compression force at the L5/S1 disc was also estimated by the system.

In the simulated clearing task, a 9 kg power saw was lifted up from the floor, and placed against a wooden bar of 211 cm above floor level. The subjects kept their feet stationary, side by side in a narrow straddle. Otherwise the work style was free. The lifting techniques used by the subjects were analyzed post-task from the video recordings and rated into four categories: back lift, leg lift, load kinetic lift, and trunk kinetic lift (Leskinen 1985).

5.2.2.4 Thermal responses (IV)

The subjects in Study IV walked twice, without and with the protective equipment, on a treadmill at a constant inclination of 8^o during the same day in random order. During the rest period between the tests HR and the rectal temperature recovered to the initial levels. The speed was increased progressively (3.0, 3.5, 4.0, and 4.5 km/h). The subjects walked for 4 min at each speed; the walking phase was preceded and followed by a 4-min rest and recovery period. The total duration of both tests was 24 min. During the test, HR and respiratory gas exchange were measured as during the measurement of $\dot{V}O_2max$.

In the test, rectal temperature was measured with a thermistor probe (YSI 401, Yellow Springs Instruments, USA) inserted 10 cm beyond the anus. The thermistor was connected to a thermometer (OLLI 293, Kone, Finland) calibrated for the YSI-thermistor. The subjects were weighed on a balance (Datex WM304, Vaisala, Finland) with an accuracy of ± 10 g in order to estimate the amount of sweating.

5.2.2.5 Perceived sensations (II, IV)

Immediately after the smoke-diving in Study II the subjects were asked their overall RPE for the cardiorespiratory system using the Borg scale from 6 to 20 (Borg 1973 and 1982). In study IV the overall RPE and the local RPE for the legs (Borg 1973 and 1982), as well as thermal sensation and thermal comfort were asked with standardized scales (Fanger 1970).

5.3 Statistical methods

In Studies I-V the statistical analyses were done by the SAS Statistical Package (SAS 1985).

Means (II-V), standard deviations (II-IV) and ranges (II,V) were used to describe the data.

In Study I the Chi-square (χ^2) test was used to evaluate the effects of age and the size of the fire department on the questionnaire responses of the fire fighters.

The relationships between the variables were evaluated with Pearson's correlation coefficients in Studies II and III.

The significances of the differences between the results of the compared groups and repeated measurements were tested with Student's *t*-test in Studies III and IV.

In Study V the dependence of assessed variables was examined with linear regression analysis.

The reliability of the job-related test drill (V) was calculated according to the procedure of Altman and Gardner (1988).

The differences were considered to be statistically significant when the p-value was less than 0.05.

6 RESULTS

6.1 The most demanding fire-fighting and rescue tasks on physical work capacity, and their frequency (I)

Smoke-diving was rated to demand most aerobic power which is necessary in long-term operations requiring heavy dynamic muscle work of the large muscle groups (80% of the respondents). Clearing debris with heavy manual tools was considered to set the highest demands on muscular performance (44% of the respondents). The need for motor coordination in roof work was evaluated to be the greatest by 78% of the respondents. The rating of the tasks on physical work capacity was not significantly affected by age (Table 5).

TABLE 5 The fire-fighting and rescue tasks rated among the three physically most demanding tasks on physical work capacity in terms of aerobic power, muscular performance and motor coordination in different age groups (% of the respondents)

Work task	Age [a] (years) 22-29 (n = 39)	30-39 (n = 62)	40-54 (n = 55)	All (n = 156)
Aerobic power				
1. Smoke-diving	72	81	85	80
2. Clearing debris	49	42	45	45
3. Internal response to a fire	31	34	16	27
4. Terrain fire	38	24	18	26
5. Scuba diving	3	14	29	17
Muscular performance				
1. Clearing debris	46	40	45	44
2. Using a set of hydraulic tools	46	31	34	36
3. Transferring a patient	38	35	31	35
4. Roof work	8	24	22	19
5. Smoke-diving	15	24	15	19
Motor coordination				
1. Roof work	67	82	80	78
2. Tackling a fire by using portable ladders	49	55	44	49
3. Smoke-diving	49	32	35	37
4. Setting up ladders	23	16	22	20
5. Clearing debris	5	21	18	16

[a]The differences between the age groups were statistically nonsignificant according to χ^2-test

Most of the respondents (83-88%) estimated that they had carried out the physically most demanding fire-fighting and rescue tasks (smoke-diving, clearing debris and roof work), on average, four times a year (once in a three-month period) during the last five years. The frequency of the tasks was not significantly related to the subject's age or to the size of the fire department (Table 6).

TABLE 6 The number and percentage of fire fighters who had done the physically most demanding fire-fighting and rescue tasks, on average, four times a year (once in a period of three months) during the last five years

Work task	Age [a] (years) 22-29 (n=11-36)		30-39 (n=6-47)		40-54 (n=9-42)		All (n=26-125)	
	n	%	n	%	n	%	n	%
Smoke-diving	32	89	39	83	33	79	104	83
Clearing debris	22	85	24	83	12	92	58	85
Roof work	31	86	38	86	38	93	107	88
Internal response to a fire	12	75	15	88	9	90	36	84
Terrain fire	12	86	14	82	9	90	35	86
Scuba diving	8	73	5	83	7	78	20	77
Using a set of hydraulic tools	17	81	21	91	11	92	49	87
Transferring a patient	18	86	20	91	11	92	49	89
Using portable ladders	19	68	28	90	14	82	61	80
Setting up ladders	9	82	8	73	7	78	24	77

[a]The differences between the age groups were statistically nonsignificant according to χ^2-test

The distribution of the work tasks among the staff was considered unequal by 92% in the large fire departments, 52% in the middle-sized ones, and 19% of the respondents in the small fire departments ($p<0.001$). Almost every respondent in the large fire department (99%) considered that they had fire fighters specialized for certain tasks. The corresponding relative proportions of the respondents serving in the middle-sized and small departments were 86% and 52%, respectively ($p<0.001$). The main reasons for specialization were evaluated to be the level of individual occupational education and training (41% of the respondents) and physical work capacity (31% of the respondents). There were no significant age-related differences in the responses concerning the distribution of the work tasks and specialization.

6.2 Physiological stress and strain during simulated smoke-diving (II)

The simulated smoke-diving in the heat lasted 13-27 min. The volume of pulmonary ventilation during the smoke-diving was 54±10 l/min and the estimated oxygen consumption was 2.4±0.5 l/min. This corresponded to 60±12% of $\dot{V}O_2max$ (range 41-101%). The HR was 150±13 beats/min (79±6% of HRmax). The peak HR was 180±13 beats/min (95±6% of HRmax) (Table 7). The peak HR of eight subjects exceeded their individual maximal HRs attained in the exercise test.

TABLE 7 Subjects' work time, calculated ventilation volume, estimated mean oxygen consumption ($\dot{V}O_2$), relative aerobic strain (%$\dot{V}O_2max$), average heart rate (HR), peak heart rate (HRpeak), relative circulatory strain (%HRmax) and overall rating of perceived exertion (RPE) during the smoke-diving task (N=35)

Variable	Mean	SD	Range
Work time (min)	17	4	13 - 27
Ventilation[a] (l/min)	54	10	40 - 97
$\dot{V}O_2$[b]			
(l/min)	2.4	0.5	1.8 - 4.3
(ml/min/kg)	31	7	22 - 55
(%$\dot{V}O_2max$)	60	12	41 - 101
HR			
(beats/min)	150	13	120 - 169
(%HRmax)	79	6	66 - 90
HRpeak			
(beats/min)	180	13	146 - 203
(%HRmax)	95	6	81 - 109
RPE[c]	14	1	11 - 15

[a]Calculated from the decrease of the air container pressures
[b]Estimated from the ventilation volumes (see Methods)
[c]Rated according to Borg (1973)

Immediately after the smoke-diving the overall RPE varied from 11 (fairly hard) to 15 (hard) (Table 6). The RPE values correlated significantly to the relative average and peak working HRs ($r=0.61$, $p<0.001$, and $r=0.36$, $p<0.05$, respectively).

6.3 Biomechanical features of the simulated clearing task in two age groups of fire fighters (III)

The younger subjects had a higher speed of movement for both back and knee extension than the older subjects, and the difference for knee extension (89.1±25.7°/s vs. 35.3±11.5°/s) was significant ($p<0.001$). The dynamic compressive force at the L5/SI disc was 5998±1029 N for the older subjects and 6392±1916 N for the younger subjects (Table 8). The dynamic compressive force of the subjects correlated significantly with the hip joint angle at the beginning of the task ($r=0.71$, $p<0.01$).

The maximal isokinetic forces of trunk and leg muscles of the subjects were assessed but due to methodological differences they were not related to the forces obtained in the clearing task.

TABLE 8 Joint angle at the beginning of the task (initial angle), speed of movement, and peak torque during back and knee extension in the task, and dynamic compressive force of the task at the L5/SI disc for the older and younger subjects; values are means ± SD

Task variable	Older (n = 6)	Younger (n = 7)
Initial angle (°)		
Hip flexion	38 ± 6	34 ± 6
Knee flexion	56 ± 24	78 ± 19
Back extension		
Speed of movement (°/s)	129.0 ± 27.3	163.9 ± 17.2
Peak torque (Nm)	234 ± 43	241 ± 51
Knee extension		
Speed of movement (°/s)	35.3 ± 11.5 ***	89.1 ± 25.7
Peak torque (Nm)	109 ± 35	128 ± 37
Compressive force at the L5/SI disc (N)	5998 ± 1029	6392 ± 1916

***$p<0.001$ according to Student's *t*-test for means

6.4 Thermal and cardiorespiratory responses during the treadmill-test (IV)

Walking on the treadmill while wearing fire-protective equipment significantly ($p<0.001$) increased the cardiorespiratory strain of fire fighters as compared to the corresponding walking exercise without protective equipment.

At the end of the exercise with the protective equipment the HR averaged 169 beats/min (87 %HRmax). Without the protective equipment the HR was 129 beats/min (67 %HRmax) (Table 9).

TABLE 9 Heart rate (HR), relative circulatory strain (%HRmax), oxygen consumption ($\dot{V}O_2$), relative aerobic strain (%$\dot{V}O_2max$), rectal temperature and blood lactate with and without the fire-protective equipment (N=12); values are means ± SD

Variable	Without	With
HR		
(beats/min)	129 ± 4	169 ± 4***
(%HRmax)	67 ± 2	87 ± 2***
$\dot{V}O_2$		
(l/min)	2.2 ± 0.1	3.0 ± 0.1***
(ml/min/kg)	26.5 ± 0.6	36.4 ± 1.0***
(%$\dot{V}O_2max$)	53 ± 2	72 ± 3***
Rectal temperature		
(°C)	37.6 ± 0.1	37.9 ± 0.1*
Blood lactate		
(mmol/l)	1.1 ± 0.2	2.5 ± 0.7

*$p<0.05$; **$p<0.01$; ***$p<0.001$ according to the Student's *t*-test for paired observations

At the end of the walking test with the protective equipment, $\dot{V}O_2$ was, on average 3.0 l/min (36.4 ml/min/kg). The relative aerobic strain was 72 %$\dot{V}O_2max$. The corresponding values without the protective equipment were 2.2 l/min, 26.5 ml/min/kg and 53% of $\dot{V}O_2max$, respectively (Table 9).

The %HRmax (circulatory/cardiac strain) and %$\dot{V}O_2max$ responses of the subjects, while wearing the protective equipment, correlated significantly to $\dot{V}O_2max$ related to body mass (r=-0.66, p<0.05 and r=-0.79, p<0.01, respectively).

At the end of the tests, a significantly (p<0.05) higher rectal temperature was observed with than without the protective equipment 37.9±0.1°C vs. 37.6±0.1°C. A significant (p<0.001) increase was noted in the votes for thermal sensation.

Body weight loss, which indicates the amount of sweating, averaged 364±24 g in the test with the protective equipment. It was significantly (p<0.001) less than that (148±17 g) in the test without the protective equipment.

6.5 Cardiac strain imposed by the job-related test drill (V)

In the tasks of the drill, the range of HR was 91-184 beats/min with a corresponding cardiac strain of 49-99% of HRmax. The highest strain was observed in the task "Going over and under bars" (73-99 %HRmax) (Table 10).

TABLE 10 Heart rate (HR) and cardiac strain (%HRmax) in the tasks of the test drill (N=59)

Task	Time (min)	HR (beats/min)		%HRmax	
		Mean	Range	Mean	Range
Walking and carrying	4	122	91-166	66	49-87
Climbing/ascending stairs	3.5	135	98-174	73	53-92
Hammering	2	150	112-184	82	63-96
Over and under bars	3	158	116-184	86	73-99
Hose rolling	2	149	100-182	81	61-99
All	14.5	140	102-175	76	59-93

The cardiac strain (%HRmax) of the drill depended significantly ($r=-0.50$, $p<0.001$) on $\dot{V}O_2max$ per body weight for bicycling. The regression equation for %HRmax was $-0.42 \times \dot{V}O_2max + 95.80$. The body weight of the subjects correlated significantly to the %HRmax during the whole drill ($r=0.26$, $p<0.05$). The %HRmax of the drill was not significantly affected by age.

The relationship between $\%\dot{V}O_2max$ for bicycling and %HRmax of the drill was significant ($r=0.78$, $p<0.001$). At the mean cardiac strain level of the drill (76 %HRmax) the $\dot{V}O_2$ for bicycling was 26 ml/kg/min and 2.1 l/min (56 $\%\dot{V}O_2max$). The regression equation for %HRmax was $0.50 \times \%\dot{V}O_2max + 48.39$.

The test-retest reliability of the test drill showed to be good (Table 11).

TABLE 11 Reliability of the job-related test drill according to the heart rate (HR) of the subjects (n=10-13); values are means ± SD

Task	HR (beats/min) 1st time	2nd time	Pearson's correlation coefficient (95% confidence interval)
Walking and carrying	117 ± 9	115 ± 9	0.68 (0.17 - 0.90)
Climbing/ascending stairs	128 ± 11	126 ± 10	0.81 (0.44 - 0.95)
Hammering	151 ± 11	150 ± 10*	0.98 (0.93 - 0.99)
Over and under bars	159 ± 10	157 ± 10	0.89 (0.67 - 0.97)
Hose rolling	144 ± 12	140 ± 16*	0.91 (0.72 - 0.97)
All	137 ± 10	135 ± 10	0.88 (0.56 - 0.97)

*p<0.05 according to Student's *t*-test for paired observations

7 DISCUSSION

7.1 Representativeness and characteristics of the subjects

The subjects of Study I represented different aged professional fire fighters from various fire and rescue departments covering all of Finland. About one-third of the subjects belonged to each age group of 22 to 29, 30 to 39 and 40 to 54 years. However, the sample size was quite small and only nine respondents (6%) were 50 to 54 years old. One reason for the low mean age of the subjects is the fire fighters' present retirement age of 58 years, and the large number of Finnish men who have retired early (Ilmarinen 1991).

The representativeness of the subjects in the sample of Study I can be considered by comparing the individual and occupational characteristics of the subjects to those of 2940 professional fire fighters on duty during the collection of the data. A reliable comparison was difficult, because there is no nationwide register on the age, period of service, distribution of the fire fighters in the fire departments etc. in Finland. However, information is available on the basic vocational education and training of professional fire fighters; 49% of them had studied at the State Fire and Rescue Institute, 19% had participated in short courses, and 31% had no basic training in fire-fighting and rescue work. The corresponding values in the sample of Study I were 62%, 7%, and 31%, respectively. In regard to vocational education and training, the differences were minor between the sample and all professional fire fighters. It is therefore likely that also other individual and occupational characteristics of the sample corresponded reasonably well to the average situation among professional fire fighters in Finland.

The response rate in Study I remained quite low (67%) in spite of a reminder and some additional actions in the largest fire department of the sample. The main reasons for the loss of respondents were probably the time of year of dispatching the questionnaires (around summer holiday season), and a local dispute about some details of the collective labor agreement in the largest fire department of the sample. The dispute prevented the returning of all 35 questionnaires sent, and reduced the response rate by some 10%.

The subjects in Studies II and IV were fit according to their $\dot{V}O_2max$. Each of the subjects in both studies exceeded the $\dot{V}O_2max$ value of 3.0 l/min, which is considered a minimum level for a fire fighter while performing smoke-diving operations (Kilbom 1980, Louhevaara et al. 1985). In Study V eight subjects had a smaller $\dot{V}O_2max$ than 36 ml/min/kg. The results of six fire fighters who passed the drill were not included in the study because they regularly used medication inhibiting HR. Furthermore, a few older fire fighters refused to participate in the study because they had some doubts about passing the drill.

The subjects in all physiological measurements had no problems with motivation, particularly the maximal exercise tests in Studies II, IV, and V succeeded completely.

The difference between the mean ages of the two groups of fire fighters in the biomechanical analysis (III) was not so large as expected. The reason for this was the high mean age (43 years) of the fire fighters at the Fire and Rescue Department of the City of Oulu.

Due to the above-mentioned reasons, the results of all these studies can be mainly generalized to apply to healthy, young, well-motivated and physically fit fire fighters. Conclusions about the relationships between the variables and age have to be drawn very carefully.

7.2 Methodological considerations

The main methods (HR and $\dot{V}O_2$ measurements) used in this study can be considered basic work physiological methods, and their reliability and validity are high under standardized conditions. All measurements were done and guided by a professional staff having several years' work experience on the use of work physiological laboratory and field methods.

The Sport-Tester PE 3000 equipment for measuring HR of the subjects in Study II functioned without technical problems during simulated smoke-diving. The overheating (technical limit: 50°C) of the equipment was prevented by placing the equipment under the protective layers as close as possible to the skin of the subjects. Without skin burns, the 50 °C limit is not possible to exceed in simulated smoke-diving. In the analysis of the HR results obtained in a hot environment, it is essential to take into consideration the effects of thermal stress on HR.

The $\dot{V}O_2$ of the subjects (Study II) was calculated from the ventilation volume, which was estimated from the pressure decreases of the air containers. The volume of the container is six litres, and the initial pressure is about 300 bars. After the work period, the pressure reading is possible to register at the accuracy of 5 bars, which is 30 l of air. Therefore, during a 15 to 20-min work period, the bias related to pulmonary ventilation per minute may be about ±2 l/min. At submaximal work levels, while $\dot{V}O_2$ ranges from 1.5 to 2.5 l/min, the ventilatory equivalent for oxygen was observed to be 20-25 l per the l/min of $\dot{V}O_2$ on a treadmill with fire protective equipment in an ambient temperature of 50°C (Ilmarinen et al., unpublished results). The level of the present estimation can be considered accurate enough for evaluating of the ventilation and $\dot{V}O_2$ of the subjects during the smoke-diving with a mean pressure decrease of about 150 bars.

The present system of biomechanical analyses has been developed recently (Study III), and the obtained results are device-specific. Due to methodological differences, the task isokinetic forces were not possible to relate to the maximal forces assessed in the test movements.

A treadmill rather than a bicycle ergometer should be used for the measurement of the $\dot{V}O_2max$ of fire fighters, because on a treadmill the fire fighters had to carry their body weight in addition to the fire-fighting equipment, as in actual operative situations.

7.3 Physical job demands and strain

7.3.1 Job demands on physical work capacity (I)

It is not suprising that smoke-diving was rated a highly demanding task in all three dimensions of physical work capacity, because in smoke-diving operations a fire fighter usually moves by walking or crawling, and carries the extra weight of his personal protective equipment and tools (total weight 25-50 kg). The visibility is usually poor, and maintaining one's balance in an unknown and hostile environment while performing given tasks requires a high level of aerobic power as well as muscle endurance and motor coordination. Moreover, heat stress may be occasionally very severe.

Some trends associated with age were discernible in the results from the smoke-diving, but they did not reach statistical significance. Smoke-diving was somewhat more frequently considered to set high demands on cardiorespiratory capacity in the age groups of over 30 years, and in medium-sized and small fire departments. The frequency of the smoke-diving tasks seemed to decrease slightly with age. It is possible that smoke-diving was evaluated more often physically strenuous by the elderly fire fighters due to their age-related decrease in cardiorespiratory capacity. Probably this was more common in the smaller fire departments where almost everyone needs to carry out all work tasks regardless of individual characteristics and work capacity. In the study of Hytten and Hasle (1989) smoke-diving and rescue work was also reported as very stressful psychologically. Age did not seem to affect the amount of perceived stress.

The clearing of debris with heavy manual tools was rated a very demanding task on physical work capacity in terms of muscular performance as well as aerobic power. Also in the questionnaire study of Purswell et al. (1991) similar tasks (e.g. forcible entry and rescue of a victim) were reported to require a considerable amount of muscle strength.

The frequency of muscularly demanding clearing tasks did not seem to decrease with age. This is in line with recent observations that the maximal muscle strength and endurance of fire fighters, based on isometric, isokinetic and dynamic repetitive tests, remained almost unchanged up to the age of 50 years (Louhevaara & Lusa 1992, Tulppo et al., unpublished results).

In the large fire departments almost every fire fighter in this study thought that the distribution of the work tasks was unequal among the staff; the operative fire fighters were oriented to perform specific tasks due to their occupational training and physical work capacity. In small fire departments, unequal distribution of the work tasks and task-oriented specialization was much less frequent than in the large ones. In the study of Purswell et al. (1991), tasks requiring much strength were most often rated to occur for several times per year, and those tasks with the greatest perceived exertion were done relatively often by only some certain respondents.

7.3.2 Simulated smoke-diving in the heat (II)

The smoke-diving in the heat lasted, on average, 17 min in Study II. According to the relative mean aerobic strain (41-101% of $\dot{V}O_2max$) and cardiac strain (66-90% of HRmax) smoke-diving can be classified as heavy or very heavy physical work (Lange-Andersen et al. 1978).

The estimated $\dot{V}O_2$ during smoke-diving (2.4±0.5 l/min) was comparable to values reported in previous studies on different fire-fighting tasks with the SCBA and fire-protective clothing (Lemon & Hermiston 1977b, Louhevaara et al. 1985, Sothmann et al. 1990).

The present HR data generally agree with the results of Davis and Dotson (1987), O'Connell et al. (1986) and Sothmann et al. (1992b) who reported very high HRs during simulated fire-fighting tasks with fire-protective equipment. One explanation for the high HRs during smoke-diving might be that the combination of heat stress and muscular work taxed the cardiovascular system more than did the exercise test. It is known that under heat stress, stroke volume is reduced and cardiac output is maintained by increasing HR (Smolander et al. 1987). Pirnay et al. (1970) have also shown that maximal HR was about 5 beats/min higher in hyperthermia compared to cooler conditions. Another explanation might be that during cycling the amount of active muscle mass is smaller than that during smoke-diving, which involves both leg and arm work (Reybrouck et al. 1975, Toner et al. 1983). In Study II, however, there were also lower HRs than previously reported, possible because the tasks in the previous studies were carried out as fast as possible, resulting in considerably shorter working times than in the present study.

There was a statistically significant, although not very powerful, correlation between the cardiac strain and RPE values in Study II. White et al. (1989) reported similar results during moderate physical exercise while wearing the SCBA and fire-protective clothing under laboratory conditions. The RPE values correlated weaker to the peak than average HRs, probably due to the short duration of work eliciting peak HRs.

Unfortunately, it was not possible to ask the subjects in Study II about their RPE during the task. The relatively low correlations between HR and RPE suggest that RPE may not be so useful to detect the level of exertion during actual smoke-diving involving multifactorial external and internal stress. During laboratory conditions contradictory results have been reported (e.g. Shimozaki et al. 1988, Sköldström 1987). This question needs further studies.

7.3.3 Biomechanical features of the simulated clearing task (III)

The estimated static compressive forces of the older and younger subjects varied from 1979 N to 3599 N and from 2110 N to 3835 N, respectively. For five of the 13 subjects, the estimated static compressive force was so high (over 3400 N) that there was an increased risk for back injury according to the NIOSH (1981) guidelines. The static compressive forces of the subjects were derived from the dynamic forces according to the results of Leskinen (1985). He showed that the static compressive force is 33-60% of the dynamic compressive force, and that the ratio predominantly depends on the lifting technique. The highest compressive forces were observed in the subjects who used the trunk kinetic lifting technique, as also shown by Leskinen (1985).

The younger subjects seemed to start the task at a smaller hip and a larger knee flexion, and they used higher segmental movement speeds. These features might increase compressive forces during lifting, as previously suggested by Hall (1985). The differences in lifting technique were probably not due to the differences in muscular performance, because the differences in muscle force and endurance were minor between the older and younger subjects. This supports the results of Heikkinen et al. (1984) who reported that maximal muscular performance starts to decrease markedly after the age of about 50 years, although a decrease in muscular performance occurs also before the age of about 50 years. The muscular performance of fire fighters seems to remain almost unchanged until the age of 50 years (Louhevaara & Lusa 1992, Tulppo, unpublished results). The slower movement speeds of the older subjects may have been due to the differences in such factors as habitual work technique, back disorders, joint flexibility and motivation. The design of this study however, did not permit further analysis of this question.

Another explanation for the slower movement speeds in older fire fighters may the decline in the speed of behavior which occurs with age (Birren & Fisher 1993). The speed of behavior can be defined as the time taken to perform all tasks or actions which require mediation by the central nervous system, such as perception, attention, memory, reasoning and simple and complex motor movements. The speed of behavior is associated with other characteristics of respiratory function and blood pressure as well as cognition. It has also been shown that physically fit individuals are faster than those who are physically less fit, and that physically fit older adults are faster than unfit young adults (Birren & Fisher 1993).

7.4 Assessment of the physical work capacity

7.4.1 Job-related treadmill test (IV)

The carrying of the extra weight of the protective equipment in the developed treadmill-test significantly increased physiological strain, compared to walking without the equipment (IV). At the end of the exercise, the difference in HR and $\dot{V}O_2$ between the tests was 40 beats/min (31%) and 0.8 l/min (36%). Similar results have been reported earlier by Sköldström (1987) and Smolander et al. (1984). The increase in rectal temperature and, in some subjects, blood lactate reflected a high strain with the protective equipment. The mean rectal temperature with the fire-protective equipment was at the same level as in the corresponding test situation in the study of White and Hodous (1987). The RPEs were not so high as would be expected on the basis of HR, as also observed by White et al. (1989). The frequent use of the protective clothing for many years perhaps influenced the perceived exertion of carrying this type of extra weight.

Lemon & Hermiston (1977b), Louhevaara et al. (1985) and Zylberstein (1973) have shown that fire-fighting tasks require a $\dot{V}O_2$ level of 2.1-2.8 l/min or in most cases from about 60% to 80% of the $\dot{V}O_2max$. The high level of $\dot{V}O_2$ is mainly caused by strenuous dynamic muscle work and the carrying of the protective equipment.

In the treadmill protocol, evaluated in Study IV the $\dot{V}O_2$ levels ranged from 2.5 to 3.4 l/min (31 to 41 ml/min/kg), and from 56 to 89 %$\dot{V}O_2max$. According to unpublished results of Louhevaara et al. the $\dot{V}O_2$ of the 342 fire fighters during the last minute of a similar test protocol were 3.1±0.4 l/min and 38.3±3.1 ml/min/kg, respectively. Thus, the demands of the protocol corresponded to the actual aerobic demands of smoke-diving, and the test is valid and reliable for assessing the cardiorespiratory capacity of operative fire fighters. In addition, compared to conventional exercise tests, the treadmill protocol is submaximal, safe, job-related, and requires neither sophisticated devices nor highly professional staff. In the simplest modification, the passing of the test guarantees a minimum level of $\dot{V}O_2max$ for smoke-diving tasks.

Many researchers (e.g. Louhevaara et al. 1985, Zylberstein 1973) have recommended that a fire fighter should have a $\dot{V}O_2max$ level of 2.8-3.0 l/min. So he/she should be able to perform bicycle ergometer exercises at a work load of 200 W for 6 min (Kilbom 1980). However, the present results indicate that it may not be appropriate to estimate a fire fighter's ability for smoke-diving only on the basis of absolute $\dot{V}O_2max$, since %HRmax and %$\dot{V}O_2max$ values correlated to relative $\dot{V}O_2max$, and not to absolute $\dot{V}O_2max$. The level of $\dot{V}O_2max$ is relevant to analyze related to body weight of a fire fighter, because it is crucial for a fire fighter's work performance to be able to carry one's own body weight, and also the weight of the fire-fighting equipment.

The results demonstrated that the developed treadmill protocol is suitable for assessing a fire fighter's cardiorespiratory capacity to perform smoke-diving tasks in a thermoneutral environment.

7.4.2 Test drill (V)

Skillful performance during the test drill may to some extent compensate impaired $\dot{V}O_2max$, because the regression equation between $\dot{V}O_2max$ per body weight and %HRmax included two 'outliers', i.e. subjects who had both a very low $\dot{V}O_2max$ in bicycling (poor cardiorespiratory capacity) and %HRmax of the drill (low cardiac strain). Especially the hammering and hose rolling tasks seemed to require more skill than the other tasks of the drill, because repeated HR measurements of the same person during these tasks varied the most according to the results of a paired t-test. Schonfeld et al. (1990) have criticized striking or moving heavy objects as simulation tasks, because the force required for these tasks can not be calibrated and can not be reproduced between subjects. Generally, however, it can be stated that the reproducibility of the test drill in this study was high according to repeated HR measurements.

The %HRmax in the drill correlated significantly to $\dot{V}O_2max$ but not to age, although $\dot{V}O_2max$, on average, decreased with age. This can be explained by the great individual variation in $\dot{V}O_2max$, which in this age range of the subjects is more dependent on physical training than on age. Also Schonfeld et al. (1990) reported that age was not a significant predictor of performance for any of the three simulated fire-fighting tasks between the age from 20 to 45 years.

Eight subjects with a $\dot{V}O_2max$ less than 36 ml/min/kg performed the drill with near maximal levels of cardiac strain. The observations of this study agree with the previous recommendations that a $\dot{V}O_2max$ for smoke-diving tasks should be at least 3.0 l/min i.e. about 36 ml/min/kg for a fire fighter weighting 75-80 kg (e.g. Louhevaara 1986, Zylberstein 1973).

There was a significant, though weak, correlation between body weight and cardiac strain during the drill. In the worksite experiments, one tall fire fighter who had a considerable amount of overweight was not able to perform the drill in a fixed maximal time of 14.5 min due to an exceptionally high consumption of air, which emptied the air container. These results confirm the previous conclusions of Davis and Starck (1980) and Davis et al. (1982b), that excessive body fat may play a dominant role in reducing performance.

The submaximality of the drill is an important feature preventing health and safety hazards. At the cardiac strain levels of 75-84, 85-94, and 95-100 %HRmax of the drill, the estimated relative aerobic strain can be classified as high (50-74 %$\dot{V}O_2max$), very high (75-89 %$\dot{V}O_2max$) and extremely high (90-100 %$\dot{V}O_2max$), respectively. A fire fighter can continuously work for over 60 min with high cardiac strain. At the very high and extremely high levels, the maximal times for continuous work are 20-30 min and 1-10 min, respectively (Louhevaara et al. 1986). If a person can not perform the drill within a fixed time of 14.5 min, or his or her cardiac strain level is 90-100 %HRmax, there are strong indications of low physical (mainly cardiorespiratory but also muscular) work capacity, which probably reduces efficiency and safety in actual smoke-diving tasks.

The HRmax of the subjects decreased with age. The results favor more the function of HRmax = 205 - (0.5 x age) for the age-related HRmax than that of HRmax = 220 - age. (Arstila et al. 1984, Mitchell et al. 1958). The differences were more pronounced in the age groups of 40-49 and 50-54 years. For the health and safety of aging fire fighters, however, lower HRmax table values, i.e. the function of HRmax = 220 - age, can be recommended for practical purposes. However, the most practical way of measuring HR during the drill is to use, for instance, a Sport Tester cardiometer which has proven to be valid and reliable in several studies (Karvonen et al. 1984, Leger & Thivierge 1988, Seaward et al. 1990, Treiber et al. 1989).

Over two-thirds of the subjects (71%) considered that the drill was a better method for assessing physical work ability than a cycle ergometer test. Almost everyone (91%) felt that the results of the drill motivated them to physical training and 90% of the subjects thought that the results of the drill are useful for the occupational health services. Also in the study of Sothmann et al. (1990) the subjects rated a fire-suppression protocol to be reasonable for the assessment of the physical work capacity of fire fighters.

The drill is a test method but it may also be used for rehabilitation, e.g., after a long sick leave. First the drill can be carried out more slowly or without the SCBA. In the future, it should be studied how this test drill functions as a follow up method of fire fighters' physical work capacity.

The drill was quite easily passed by the subjects having a $\dot{V}O_2max$ over 40 ml/min/kg in ergometer bicycling and the test drill efficiently sorted out the subjects according to their $\dot{V}O_2max$. The advantages of this test drill are it's relevancy to actual smoke-diving, submaximality, safety and non-competitiveness. Fire fighters can easily understand their results of the test, and to relate these to their personal maximal level. The test drill is also easy to put into practice at every fire station and it is cheap. The current results and experiences from the field indicate that the developed test drill is a good method for assessing the physical work capacity of fire fighters for smoke-diving tasks.

7.4.3 Current guidelines for the selection and follow-up of the physical work capacity of Finnish fire fighters

The Guide for Smoke-diving (1991) gives a recommendation for a four-stage scale to classify fire fighters' aerobic and muscular capacity in the tests recommended by the Finnish Institute of Occupational Health (Table 12). According to the Guide, fire fighters in the age range of 20-63 years are considered sufficiently physically fit for smoke-diving tasks, if they attain a "good" result in each test. This recommendation can be neglected in specific situations which have been described and discussed in the Guide.

The tests and their classification in Table 12 are based on the results of this research project, on population studies (Rusko et al. 1976, Shvartz & Reibold 1991), and on the pilot studies carried out at the Rescue Department of the City of Helsinki and the State Fire and Rescue Institute (Louhevaara et al. 1991).

The tests are mainly designed to follow up the fire fighters' physical work capacity. These tests are also used for the selection of applicants for fire-fighting training courses. They should attain the results determined by the State Fire and Rescue Institute. In the actual selection of applicants for basic training courses, the required level has been between "good" and "excellent" in each test (Louhevaara et al., unpublished results).

TABLE 12 Tests and their classification for the assessment of fire fighters' aerobic and muscular capacity

Test	Classification Poor	Moderate	Good	Excellent
$\dot{V}O_2max$[a]				
(l/min)	≤ 2.4	2.5 - 2.9	3.0 - 3.9	≥ 4.0
(ml/min/kg)	≤ 29	30 - 35	36 - 49	≥ 50
Bench press (45 kg)				
(reps/60 s)	≤ 9	10 - 17	18 - 29	≥ 30
Sit-up				
(reps/60 s)	≤ 20	21 - 28	29 - 40	≥ 41
Pull-up				
(max reps)	≤ 2	3 - 4	5 - 9	≥ 10
Squatting (45 kg)				
(reps/60 s)	≤ 9	10 - 17	18 - 26	≥ 27

[a]Bicycle-ergometer or treadmill test

8 CONCLUSIONS AND RECOMMENDATIONS

From the present study the following conclusions and recommendations can be drawn:

1) The job demands on physical work capacity remain high during the occupational career of fire fighters. Detection of reduced work capacity is necessary, and efficient preventive measures for promoting health and physical work capacity should be commenced as early as possible, particularly among elderly and/or unfit fire fighters for ensuring safety at work.

2) Simulated smoke-diving in the heat, which requires the use of the self-contained breathing apparatus and fire protective clothing, is physiologically very demanding for all fire fighters regardless of age and fitness. The near maximal or maximal heart rates were mainly due to strenuous dynamic muscle work and the wear of heavy personal protective equipment, as well as to heat stress. The results emphasize the need to evaluate regularly the health and physical fitness of every fire fighter who has to carry out smoke-diving tasks.

3) The lifting and handling of a power saw, which is a typical task in fire-fighting and rescue work produced a high load on the musculoskeletal system of the older and younger groups of fire fighters. The results emphasize the importance of good muscle performance and proper work techniques in fire-fighting and rescue operations requiring the use of heavy manual tools.

4) The demands of the developed job-related treadmill protocol corresponded well to the actual aerobic demands observed during smoke-diving. Therefore, it can be used for the assessment of fire fighters' cardiorespiratory capacity for actual smoke-diving tasks.

5) Thermal strain in a thermoneutral environment does not limit the physical work performance of a fire fighter, if his cardiorespiratory system is capable of carrying the extra weight of fire-protective equipment during strenuous muscular work.

6) The developed and evaluated job-related test drill proved to be valid and feasible for the worksite assessment of the fire fighters' physical work capacity for smoke-diving tasks.

Recommendations for further research

In addition to these conclusions, further studies can focus on the following questions:

- How can the developed test drill reveal the changes in the physical work capacity of fire fighters in the long-run, and what other factors are related to the strain in the drill (e.g. musculoskeletal symptoms or disorders)?
- What is the role of the motor coordination of fire fighters, with regard to safer work, e.g., preventing injuries?
- What is the strain caused by the use of current chemical-protective clothing, since their use will increase among fire fighters in the future?
- What is the thermal strain in consecutive fire-fighting and rescue operations in the heat?
- What is the role of rest and work periods on the strain of fire fighters in physically demanding operations?
- What is the best way to participate in the preparation and application of European Community Standards and Directions of fire-fighting and rescue work?

YHTEENVETO

Vaativista ja usein vaarallisista palo- ja pelastustehtävistä suoriutuminen edellyttää palomiehiltä korkeaa ammattitaitoa, hyvää terveydentilaa sekä keskimääräistä parempaa fyysisistä ja psyykkistä toimintakykyä.

Palo- ja pelastustoimessa on jatkuvasti kehitetty työmenetelmiä ja teknistä laitteistoa. Vasta viime vuosina on kiinnitetty enemmän huomiota palomiesten yksilöllisiin ominaisuuksiin. Toimessa olevien palomiesten keski-ikä nousee nopeasti, mikä lisää ennaltaehkäisevän terveyttä ja toimintakykyä ylläpitävän toiminnan tarvetta. Ikääntymiseen ja fyysiseen toimintakykyyn liittyvät ongelmat vaikeuttavat toimintaa erityisesti pienissä palolaitoksissa, joissa jokaisen palomiehen pitää pystyä selviytymään kaikista palo- ja pelastustehtävistä. Suomessa palomiesten työkyvyn arviointi on epäyhtenäistä. Työterveyshuollosta ja palomiesten työturvallisuudesta vastaavilla henkilöillä ei ole aina mahdollisuuksia perehtyä erilaisten palo- ja pelastustehtävien vaatimuksiin, mikä vaikeuttaa työkyvyn arvioimista luotettavien työstä johdettujen kriteerien perusteella.

Tämän tutkimuksen tavoitteena oli selvittää palomiestyön fyysisiä vaatimuksia toimintakyvyn kannalta, vaativimpien tehtävien fyysistä kuormittavuutta sekä kehittää ja arvioida menettelytapoja savusukelluskelpoisuuden arvioimiseen palomiesten työkyvyn ja työturvallisuuden parantamiseksi. Tavoitteeseen edettiin selvittämällä kyselytutkimuksella palo- ja pelastustehtävien fyysiset toimintakykyvaatimukset, vaati-

vimpien työtehtävien fyysinen kuormittavuus sekä kehittämällä ja arvioimalla laboratorio- ja kenttätestejä palomiesten verenkiertoelimistön toiminta- ja työkyvyn arvioimiseen.

Suomen kaikki palolaitokset kattavassa kyselytutkimuksesa 156 palomiestä arvioi palo- ja pelastustehtävien asettamat vaatimukset fyysiselle toimintakyvylle verenkiertoelimistön (aerobinen teho), liikuntaelinten (lihasvoima ja -kestävyys) ja hermoston (sensomotorinen toiminta) toiminnan kannalta. Lisäksi he arvioivat eri tehtävien esiintymistiheydet. Eniten verenkiertoelimistön toimintakykyä vaativana tehtävänä pidettiin savusukellusta, jonka 80% palomiehistä sijoitti kolmen vaativamman työtehtävän joukkoon. Vastaavasti liikuntaelinten toimintakykyä arvioitiin vaativan eniten pelastus- ja sammutusraivauksen (44%) ja sensomotorista toimintaa (koordinaatiota, ketteryyttä, tasapainoa) kattotyöskentelyn (78%). Viimeisen viiden vuoden aikana 83-88% palomiehistä ilmoitti tehneensä näitä työtehtäviä keskimäärin neljä kertaa vuodessa. Ikä ei vaikuttanut arvioihin työtehtävien kuormittavuudesta eikä työtehtävien esiintymiseen.

Savusukelluksen aiheuttamaa fyysistä kuormittavuutta arvioitiin tehtävässä, jossa simuloitiin uhrin (70 kg painava nukke) pelastustehtävää laivatulipalossa savusukellusvarustuksessa. Tehtävään osallistui 35 palomiesoppilasta, jotka olivat 19-27 vuotiaita. Keskimäärin 17 minuuttia kestäneessä tehtävässä keskimääräinen keuhkotuuletus oli 54 l/min ja sen perusteella arvioitu hapenkulutus oli 2,4 l/min (60% maksimaalisesta hapenkulutuksesta). Koehenkilöiden keskimääräinen sydämen sykintätaajuus oli 150 lyöntiä/min (79% maksimaalisesta sykintätaajuudesta) ja huippusykintätaajuus 180 lyöntiä/min (95% maksimaalisesta sykintätaajuudesta).

Biomekaanista kuormittavuutta arvioitiin simuloidussa raivaustehtävässä, joka käsitti sisäkaton aukaisun moottorisahalla. Koehenkilöinä oli kuusi vanhempaa (keski-ikä 47 vuotta) ja seitsemän nuorempaa (keski-ikä 32 vuotta) palomiestä. Moottorisahaa (paino 9 kg) nostettaessa keskimääräinen dynaaminen kompressiovoima alaselän L5/S1-nikamavälilevyyn oli 6228 N. Kompressiovoimassa ei ollut eroa vanhempien ja nuorempien palomiesten välillä. Nuoremmat palomiehet käyttivät merkitsevästi suurempia liikenopeuksia polvien ojennuksessa kuin vanhemmat. Viiden koehenkilön selän staattinen kompressiovoima, arvioituna dynaamisesta kompressiovoimasta, ylitti 3400 N enimmäissuositusrajan, jonka ylittämisen jälkeen selän vammautumisriski kasvaa merkitsevästi.

Tutkimuksessa kehitetyssä täydessä savusukellusvarustuksessa tehtävässä kävelytestissä juoksumatolla saavutettiin keskimäärin aikaisemmin kirjallisuudessa raportoidut savusukeltavilta palomiehiltä vaadittavat maksimaalisen hapenkulutuksen tasot (3,0 l/min ja/tai 36 ml/min/kg). Testissä koehenkilöt kävelivät 8 asteen nousukulmassa neljällä eri nopeudella (3,0, 3,5, 4,0 ja 4,5 km/h) kullakin neljän minuutin ajan. Savusukellusvarustus aiheutti 12 kokeneelle palomiehelle hapenkulutuksessa 0.8 l/min (36%) ja sydämen sykintätaajuudessa 40 lyöntiä/min (31%) lisäyksen raskaimmalla työkuormalla verrattuna vastaaviin mittauksiin urheiluvarustuksessa.

Tutkimuksessa kehitettiin myös savusukellusta simuloiva testirata, joka koostuu viidestä tehtävästä: kävely ja kantaminen, portaiden nousu, moukarointi, ryömintä ja letkun rullaus. Koko testin ja jokaisen tehtävän suorittamisaika on vakioitu. Sydämen sykintätaajuuden perusteella testiradan toistettavuus todettiin hyväksi. Tutkimuksessa koehenkilöinä olleiden 59 kokeneen palomiehen (keski-ikä 39 vuotta) keskimääräinen sydämen sykintätaajuus oli radan tehtävissä 91-184 lyöntiä/min, mikä vastasi 49-99% maksimaalisesta sykintätaajuudesta. Korkeimmat sykintätaajuudet (73-99% maksimaalisesta sykintätaajuudesta) saavutettiin ryömintä tehtävässä. Testiradalla mitatut yksilölliset sydämen sykintätaajuudet olivat merkitsevästi yhteydessä ruumiin painoon suhteutettuun maksimaaliseen hapenkulutukseen. Testiradalla saavutettuja keskimääräisiä sykintätaajuuksia vastaavat sydämen sykintätaajuudet saavutettiin polkupyöröergometrityössä, kun hapenkulutus oli 2,1 l/min (26 ml/min/kg).

Johtopäätöksinä voidaan todeta, että palomiestyön fyysiset toimintakykyvaatimukset säilyvät korkeina koko työuran ajan. Fyysisesti varsin raskaita työtehtäviä ovat erityisesti verenkiertoelimistöä usein maksimaalisesti kuormittava savusukellus ja liikuntaelimiä ja erityisesti selkää kuormittavat raivaustehtävät. Tutkimuksessa kehitetyllä savusukellusvarustuksessa tehtävällä juoksumattotestillä ja testiradalla voidaan luotettavasti arvioida palomiesten verenkiertoelimistön toimintakykyä ja selviytymistä todellisesta savusukellustehtävästä, jossa huomattavan lisäkuormituksen aiheuttaa raskaiden suojavaatteiden ja paineilmasäiliölaitteen (25-28 kg) käyttäminen. Savusukellusta simuloivat testit antavat luotettavaa ja käyttökelpoista tietoa palomiesten yksilöllisestä toimintakyvystä työterveyshuollolle, palomiehille ja esimiehille, jotka vastaavat toiminnasta ja turvallisuudesta käytännön palo- ja pelastustehtävissä.

Jatkossa pitäisi selvittää mm., miten hyvin testirata toimii yksilöllisessä toimintakyvyssä tapahtuvien muutosten seurannassa pitkällä aikavälillä ja mihin muihin tekijöihin (esim. liikuntaelinvaivoihin) testiradalla selviytyminen on yhteydessä. Edelleen olisi tärkeää selvittää, mikä merkitys on palomiesten motorisilla taidoilla toimintakykyyn ja työturvallisuuteen. Lisääntyvien kemikaalialtistusten vuoksi muutkin kuin savusukeltavat palomiehet joutuvat käyttämään entistä enemmän suojavarusteita. Tällöin myös työn fyysinen kuormittavuus lisääntyy.

Miten kemikaalisuojapuvun suojausteho ja käytön kuormittavuus optimoidaan edellyttää lisätutkimuksia. Myös useampien peräkkäisten työskentelyjaksojen ja eripituisten palautumisaikojen vaikutukset kuormitukseen sekä suojavarusteiden käytön aiheuttama lämpökuormitus erityisesti kuumissa savusukellustehtävissä tarvitsee lisätutkimusta. On myös osallistuttava Euroopan yhteisön standardien kehittämiseen ja soveltamiseen palo- ja pelastusalalla.

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ORIGINAL PAPERS

I

Are the job demands on physical work capacity equal for young and aging firefighters?

by

Sirpa Lusa, Veikko Louhevaara & Kari Kinnunen

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II

Physiological responses of firefighting students during simulated smoke-diving in the heat

by

Sirpa Lusa, Veikko Louhevaara, Juhani Smolander,
Mika Kivimäki & Olli Korhonen

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III

Biomechanical evaluation of heavy tool-handling in two age groups of firemen

by

Sirpa Lusa, Veikko Louhevaara, Juhani Smolander, Kari Kinnunen,
Olli Korhonen & Jouko Soukainen

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IV

Thermal effects of fire-protective equipment during job-related exercise protocol

by

Sirpa Lusa, Veikko Louhevaara, Juhani Smolander, Tiina Pohjonen,
Harri Uusimäki & Olli Korhonen

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V

Development and evaluation of a test drill for assessing physical work capacity of fire-fighters

by

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