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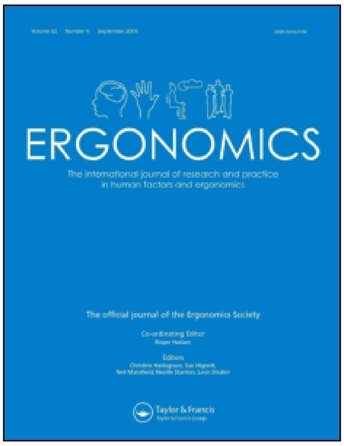

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The physical demands upon (Dutch) fire-fighters in relation to the maximum acceptable energetic workload

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Keywords: Fire-fighters; Physical demands; Energetic workload; Maximum acceptable energetic workload.

The aim of this study was to assess the tasks and activities that make physical demands on Dutch fire-fighters and to compare them with a guideline related to the development of excessive fatigue. The occupational physical demands on Dutch fire-fighters were assessed by conducting a task analysis during 85 24-h shifts. While workplace observations on the duration and frequency of physical tasks and activities were recorded, the heart rate was measured. This was then used to calculate the heart rate reserve percentage (%HRR) for predefined working periods, tasks and activities during 24-h shifts. The findings indicate that actual fire-fighting during 24-h shifts is characterised by a low frequency of incidents, a short 'turn-out' time, short tasks, and activities with a moderate to occasionally high energetic workload. Two tasks which sometimes occur in actual fire-fighting exceeded the guideline on energetic workload. The conclusion was that, though the number of incidents and the occupational demands are low during 24-h shifts, the peak loads for these two tasks are energetically high and could lead to excessive fatigue. Consequently, attention may need to be paid to health surveillance for persons exposed to such energetic peak loads, the development of physical and medical selection procedures, training, and workplace adjustments.

1. Introduction

Fire-fighting is reportedly a physically and mentally demanding job (Barnard and Duncan 1975, Davis *et al*. 1982, Gledhill and Jamnik 1992). Moreover, accidents, high injury rates, musculoskeletal and health complaints and sudden premature deaths have all been recorded for fire-fighters (Mastromatteo 1959, Bates 1987, Orris *et al*. 1995). The strenuous occupational demands of actual fire-fighting undoubtedly increase the fire-fighter's risk of developing these complaints (Orris *et al*. 1995). Short and frequent energetic peak loads during 'smoke diving', in particular, have often been cited as a cause of individual physical overload (Lusa *et al*. 1991, 1993).

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Intermittent high-energetic work increases the heart rate, and may cause fatigue, over-exhaustion and a lower cognitive performance, possibly leading to human errors and/or accidents (Kivimäki and Lusa 1994, Wu and Wang 2001). As in other emergency services (e.g. police and ambulance work), the emergency nature of fire-fighting is characterised by irregular incidents during day and night shifts. Actual fire-fighting is characterised by variable working conditions and unpredictable and heavy physical demands. The combination of irregular working hours and extra-high energetic peak loads during incidents on a 24-h shift might lead to symptoms of fatigue. But that is not all, for the heavy physical exertion required during peaks of high-intensity work could trigger acute myocardial infarction (Mittleman *et al*. 1993, Jensen-Urstad 1995, Franklin *et al*. 1997, Claessens *et al*. 2000). These observations indicate that fire-fighting can be considered as an 'at risk' job.

To prevent individual health complaints and to minimise individual physical overload it is essential to strike an optimal balance between the working conditions and the fitness of the employee. Moreover, information on the physical demands of the job and the workload is needed for the development of physical and medical selection procedures, health surveillance, training, and work adaptation (Bos *et al*. 2002). Then, studies can be carried out to determine whether the occupational demands can explain the development of excessive fatigue. The energetic workload guideline of Wu and Wang (2001, 2002) sets a limit for preventing excessive fatigue by assessing the maximum acceptable work duration (MAWD) on the basis of the energetic intensity of the work. The MAWD can be regarded as the maximum period of time in which an individual can sustain a given energetic workload without developing excessive fatigue (Wu and Wang 2001, 2002). This guideline characterises excessive fatigue by the presence of a markedly higher heart rate (HR) after working periods compared with a steady HR at the beginning.

Until now, few studies have attempted to perform task analyses or identify 'at risk' tasks and activities. Most of the studies in the past have assessed the response of the HR and the oxygen consumption of fire-fighters engaged in physical work during an alarm or a single fire-fighting incident (Barnard and Duncan 1975, Kuorinka and Korhonen 1981, Puterbaugh and Lawyer 1983, Romet and Frim 1987, Sothmann *et al*. 1992). Furthermore, many simulations have been carried out concerning fire-fighting suppression tasks in order to assess physical workload (Louhevaara *et al*. 1985, O'Connell *et al*. 1986, Misner *et al*. 1987, Sothmann *et al*. 1991, Gledhill and Jamnik 1992, Gilman and Davis 1993, Lusa *et al*. 1993, Puttiger 1994, Bennett *et al*. 1995, Smith *et al*. 1996, 1997, 1998, 2001, Carter *et al*. 1999, Williford *et al*. 1999, Oldham *et al*. 2000, Petersen *et al*. 2000, Bilzon *et al*. 2001). However, no-one has as yet performed detailed task analyses at the workplace during 24-h shifts. None of the past studies included specific information on occupational demands in order to gain more insight into the work, such as the number and duration of incidents, or the frequency and intensity of the physical tasks and activities during 24-h shifts.

This study assesses the physical demands and energetic workload during the time that passes between the moment that the alarm sounds at the fire station and the moment the fire engine returns (this period is called 'turn-out'). It is conceivable that the most physically demanding periods, tasks and activities occur within the 'turn-out' period. The overall aim of this study was to assess the physically demanding tasks and activities of Dutch fire-fighters and to compare them with the forementioned MAWD guideline. The following questions were formulated to achieve this:

- To what extent does 'turn-out' occur during normal 24-h shifts?
- What is the duration, frequency and intensity of physical tasks and activities during 24-h shifts?
- Does energetic overload occur during 'turn-out' on 24-h shifts?

2. Method

2.1. *The design of the study*

A field study was carried out during 85 24-h shifts in fire stations of cities scattered throughout The Netherlands. The aim was to:

(1) register the number of incidents and the duration of 'turn-out' time during 24-h shifts;
(2) quantify the duration and frequency of the physical demands upon Dutch fire-fighters by performing a task analysis;
(3) assess the energetic workload imposed by the physical demands of the job.

The physical work demands (defined as the duration and frequency of physical tasks and activities) placed on one fire-fighter were observed in detail during each shift. The energetic workload was measured for all the members (usually five) of the fire-fighting team which went on the fire engine during 'turn-out' time. Energetic workload was defined as the mean percentage heart rate reserve (%HRR; Karvonen *et al*. 1957, Swain *et al*. 1998) during the working periods, tasks and activities in 24-h shifts. The mean and the peak energetic workload during the working periods and tasks were compared with the energetic workload guideline of Wu and Wang (2001, 2002). This guideline consists of prediction models on the relationship between the %HRR and the maximum acceptable work duration (MAWD) for both short and long periods of work.

2.2. *Subjects*

To be sure of a heterogeneous research population, the study included fire-fighters randomly selected from small and large cities scattered over different parts of The Netherlands. Both professional and volunteer fire-fighters were included in the study. Professional fire-fighters usually work at the fire station according to a weekly work schedule, while volunteers can be called up from home or other jobs on fixed days or periods if an incident occurs. Information on the gender, age, height, weight and body mass index (BMI) of the subjects was gathered prior to the shifts. All the participants signed an Informed Consent form before the measurement started.

2.3. *Recording of work demands and energetic workload*

In The Netherlands a fire-fighting team consists of the 'driver-engine attendant', the two 'lead hands' and the two 'fire-fighters on water collection'. These positions in the fire-fighting team were randomly observed with a ratio of 1 : 3 : 3 respectively during the 85 shifts. The 'driver-engine attendant' was observed relatively less because the variation of physical tasks and activities was less compared with those of the other team members.

When the fire-fighting team was called up, one observer went along on the fire engine to record observations on the physical demands of one fire-fighter of the team. The heart rates of all the team members were measured and recorded every 5 s. The observations were carried out during 'turn-out' time (the time that passes between the sounding of the alarm and the moment the fire engine returns to the station). 'Turn-out' time was split into physically demanding working periods, as: 'from alarm to turn out', 'driving to the incident', 'working on the spot', and 'returning to the fire station'. Each period was defined, as for example 'Working on the spot': the time that passes between the moment the fire engine arrives 'on the spot' and the moment it withdraws. In this study the demands and workload during the working periods 'from alarm to turn out' and 'working on the spot' were explored in more detail. During 'on the spot' periods the fire-fighter was observed, with due consideration for the safety of the observer. For instance, when a fire-fighter entered a building to tackle a fire the observer stayed outside. Qualitative information about the type of physical activities was gathered as quickly as possible after the incident by holding an interview with the team members, but quantitative information on duration was not assessed at this point. The HR was however measured.

The working periods were then subdivided into demanding activities. Sitting, standing and walking did not count as physically demanding activities in this study. The variables and the categories within variables that were observed during the working period 'Working on the spot' are listed in table 1. The duration of working periods, physical tasks and activities was observed on a real-time basis using TRAC (Task Recording and Analyses on Computer) (Frings-Dresen and Kuijer 1995). TRAC is a method of direct observation in which the recordings are made with a small pocket computer (Psion Organizer) with keys that can be freely defined.

To assess the percentage heart rate reserve (%HRR) the HR of the five team members was continuously recorded and averaged every 5 s using a small computerized recorder (Polar Team® System, Polar Electro Oy, Finland). The resting heart rate level (HRrest) of all the fire-fighters was measured during sleep periods at the fire station (during the night) and was defined as the lowest recorded mean HR during 5 min. The maximum heart rate (HRmax) was estimated by subtracting the age of the worker from 220 (Åstrand and Rodahl 1986). The corresponding %HRR during the working periods, tasks and activities was calculated with the following formula (Karvonen *et al.* 1957):

$$\%\text{HRR} = (\text{HRwork} - \text{HRrest})/(\text{HRmax} - \text{HRrest}) \quad (1)$$

Table 1. Variables and categories within variables that were observed during the 'on the spot' working period

Variables	Categories within variables
Tasks within the 'on the spot' working period (minutes)	Preparation, inside, tasks connected with wearing the self-contained breathing apparatus (SCBA tasks), working on the water collection, forcing entry, extinguishing, operating, providing assistance, diving
Activities within tasks (seconds)	Walking, standing, running, pushing, pulling/dragging, lifting/carrying, stooping, kneeling/squatting, climbing/clambering, walking on stairs/ladders, opening, hoisting, sitting, swimming and 'other physical activities', crawling

in which HRmax is the maximum heart rate, and HRrest is the resting heart rate. HRwork was the heart rate recorded during work.

2.4. *Data analyses and statistics*

All data were checked for accuracy and analysed with SPSS 10.0 and Microsoft Excel 2000. To make sure that the results were not based on single observations, there had to be at least an arbitrary number of five observations for all the variables before the data of a particular variable could be used in the analyses. The number of incidents, the physical demands (in terms of duration, frequency of working periods, tasks and activities) and the energetic workload during 24-h shifts were analysed. In addition, to ascertain whether the measurements for the independent variable 'duration' were sufficient, a bootstrap analysis was applied to study the influence of the number of observations on the stability of the estimated mean (Efron and Tibshirani 1986, Hoozemans *et al.* 2001). Finally, calculations were performed to find out whether the energetic workload guideline was exceeded. The different calculations and statistical analyses are described for the measured variables.

2.4.1. *The number of incidents*: The number of incidents during 24-h shifts was registered. The mean, standard deviation and range of the total number of incidents during all 24-h shifts were calculated. For the further analyses of the data on physical work demands and energetic workload only the shifts in which an incident occurred were used.

2.4.2. *Work demands and energetic workload*

2.4.2.1. *Bootstrap analysis*: The bootstrap analysis was used to calculate the minimum number of observations that is needed for reliable measurements of the following independent variables: duration of 'turn-out' time, 'alarm – turn out' and 'on the spot'. The bootstrap method estimates the sampling distribution of the exposure measures by means of a large number of simulations based on sampling with replacement from the original observational data. The MATLAB 5.1© program (and a self-written syntax) was used to calculate the bootstrap.

2.4.2.2. *Duration of working periods, physical tasks and activities during 24-h shifts*: To assess the mean duration of 'turn-out' time, 'alarm – turn out' and 'on the spot', and physical tasks (within these working periods) and activities during 24-h shifts, the durations of these variables were aggregated for all 24-h shifts.

2.4.2.3. *Energetic workload of working periods, physical tasks and activities during 24-h shifts*: To analyse the data, the recordings of the real-time observations of the duration and HR during working periods, tasks and activities were transferred to a personal computer. Since these recordings were made simultaneously at the workplace, combined analysis of both duration of working periods, tasks and activities and HR was possible by means of (an additional program of) TRAC.

The time-weighted mean of the %HRR, the standard deviation and the range (minimum to maximum) were calculated during 'alarm-turn out' and 'on the spot', and for the tasks and activities during 24-h shifts. The time-weighted mean of the %HRR was calculated as follows: first, each time a variable was observed, the duration of these variables for all 24-h shifts was multiplied by the corresponding

%HRR values. Second, the products were added up for each variable. Third, these products were divided by the total duration of this variable within 24-h shifts.

2.4.3. *Energetic workload guideline*: In order to compare the mean and extreme values (energetic peak loads) of the duration of working periods and tasks during actual fire-fighting with the corresponding MAWD the following calculations were performed. First, in order to assess energetic peak loads, the extreme values for %HRR of 'alarm – turn out' and 'on the spot' and the tasks were calculated by assessing the 90th percentile values of %HRR for these working periods and tasks. The 90th percentile is the value above which 10% of the observed cases fall. Second, to calculate the MAWD the mean and 90th percentile values of %HRR were substituted into the following equations (from Wu and Wang 2001, 2002) for shorter (2) and longer (3) durations of work respectively (Range of MAWD and %HRR are prescribed for each equation).

$$\text{MAWD} = -2.67 + \exp(7.02 - 5.72{*}\%\text{HRR}) \qquad (2)$$
$$(\text{Range MAWD: } 0 - 50 \text{ min, Range \%HRR: } 50 - 100)$$

$$\text{MAWD} = 26.12\text{e}^{-4.81(\%\text{HRR})} \qquad (3)$$
$$(\text{Range MAWD: } 0 - 10 \text{ h, Range \%HRR: } 20 - 70)$$

3. Results

3.1. *Subjects*

A total of 273 fire-fighters from 20 different fire stations in The Netherlands who worked in 24-h shifts and were part of the fire-fighting team during the study signed an Informed Consent form. Furthermore, although all 273 fire-fighters were 'on duty' and ready to turn out for active fire-fighting during the study, the HR of only 222 fire-fighters was measured during incidents. Therefore, the characteristics of the 222 subjects are shown in table 2. The mean age, height, weight and body mass index (BMI) of the 222 subjects were 34.6(± 8.1) years, 1.8(± 0.1) m, 81.8 (± 10.4) kg and 25 (± 2.5) kg/m^2. The group consisted of 171 fire-fighters below the age of 40 and 51 above the age of 40. There were 10 female and 212 male fire-fighters.

3.2. *Task analyses*

3.2.1. *Number of incidents*: The mean number of incidents was 1.5 (range: 0 – 7) during the 24-h shifts.

3.2.2. *Duration of working periods, tasks and activities*

3.2.2.1. *Bootstrap analysis*: For the duration of 'turn-out' time, 'alarm-turn out' and 'on the spot', the variation round the bootstrap mean stabilised after 20, 25 and

Table 2. Characteristics of the fire-fighters present at incidents (n = 222)

	Mean	SD
Age (years)	34.6	8.1
Height (m)	1.80	0.1
Weight (kg)	81.8	10.4
BMI (kg/m^2)	25.0	2.5

30 observations respectively. As more observations (119 measurements) were recorded for each of these variables, the bootstrap analysis indicates that sufficient measurements were taken for a reliable estimate of the mean and the extreme values of the duration of tasks and activities.

The duration (and corresponding standard deviation (SD)) of 'turn-out' time was 88 (SD:76) min with a range of 11–481 min. The duration for 'alarm–turn out' was 178 (SD:134, $n = 55$) s with a range of 1–584 s and for 'on the spot' was 58 (SD:71, $n = 54$) min with a range of 3–479 min. The mean, standard deviation (SD) and range of the durations of tasks and activities within the 'on the spot' working period are shown in table 3. For example, the task with the longest duration was 'preparation', which had a mean of 35 (SD: 41) min and a range of 3–254 min. Furthermore, the duration of the activity 'lifting' (within the task 'extinguish') was 196 (SD: 165) s, with a range of 11–468 s. No physically demanding activities were observed for the task 'operate'. The task 'diving' and the activities 'swimming' and 'hoisting' did not occur during the observed 24-h shifts. The fire-fighters reported afterwards in the interviews that there was a large variation of tasks and activities within the 'Inside and SCBA' tasks. Some of the most frequently reported tasks are forcing an entry, rescuing persons, assistance (first aid to victims), extinguishing, ventilating, investigating/searching the building and 'smoke diving'. Some of the most frequently reported activities are walking on stairs (to the first, second or third floor), stooping, pulling or dragging hoses/persons, lifting loads, forcing entry with a large axe or hammer, kneeling/squatting, and opening windows with a crowbar.

3.2.3. *Energetic workload*: The mean, standard deviation (SD) and range of percentage heart rate reserve (%HRR) for the working periods, tasks and activities (within tasks) during 24-h shifts are presented in table 4. In principle, 595 data (119 incidents * five team members) with respect to %HRR for working periods would have to be available, measured during the 85 24-h shifts of the 222 fire-fighters involved. The discrepancy between the data of the subjects (595) and the number of fire-fighters (222) can be explained by the fact that several members of the team of a particular fire station were measured more than once during several shifts in different situations. Due to missing values, 429 data (derived from 222 subjects) were available to calculate the mean %HRR for the working periods 'Working on the spot' and for 'From alarm to turn out', measured during 52 and 53 24-h shifts respectively. The mean %HRR varied from 26.4% for the 'alarm–turn out' working period to 30.6 for the 'on the spot' working period (see table 4). Also, the mean % HRR with respect to the tasks and the activities within the 'working on the spot' working period is shown in table 4. The mean %HRR of the task (within 'working on the spot') with the highest %HRR (SCBA) was 58.4(19.1) with a range of 30.3–92.0%HRR. Walking on stairs was the activity with the highest mean and the highest range (14.1–86.1%HRR) of the %HRR within the 'working on the spot' working period.

3.3. *Comparison with workload guidelines*

The 'Inside and SCBA' tasks exceeded the MAWD on the basis of the 90th percentile value of the real duration. The real duration of the 'Inside and SCBA' tasks were 23 and 21 min; the corresponding MAWDs are 17 and 4 min respectively.

Table 3. Duration of tasks (minutes) and activities (within tasks) (seconds). The table shows the number of 24-h shifts that were used for the calculations (#) in each case. In the first row the total duration of tasks is sorted (from left to right) from tasks of longer duration (left) to tasks of shorter duration (right). The activities are sorted from tasks of longer duration (above) to tasks of shorter duration (below)

	Activities (within tasks)											
	Preparation		Inside		SCBA tasks		Water-collection		Operate		Extinguish	
	M (SD), *Range*	*n*	M (SD), *Range*	*n*	M (SD), *Range*	*n*	M (SD), *Range*	*n*	M (SD), *Range*	*n*	M (SD), *Range*	*n*
Total duration of tasks (minutes)	35 (41) *3 – 254*	54	13 (10) *0 – 37*	25	12 (15) *1 – 39*	15	8 (11) *0 – 44*	29	3 (7) *1 – 11*	14	3 (3) *1 – 6*	12
Duration of activities (seconds)												
Other physical activities	–	–	688(618) *8 – 2143*	23	722 (876) *77 – 2365*	15	–	–	–	–	–	–
Lifting/carrying	207 (273) *8 – 1289*	29	–	–	–		132 (126) *9 – 504*	23	–	–	196 (165) *11 – 468*	12
Stooping	42 (57) *1 – 251*	36	–	–	–		96 (116) *2 – 353*	16	–	–	–	–
Kneeling/squatting	25 (23) *1 – 76*	14	–	–	–		90 (97) *2 – 235*	7	–	–	–	–
Pulling/dragging	15 (13) *2 – 39*	14	–	–	–	–	58 (85) *7 – 353*	24	–	–	–	–
Walking stairs	56 (54) *3 – 311*	15	–	–	–	–	19 (18) *1 – 57*	5	–	–	–	–
Running	42 (114) *4 – 264*	10	–	–	–	–	–	–	–	–	–	–
Pushing	31 (43) *2 – 162*	12	–	–	–	–	–	–	–	–	–	–
Crawling	79 (117) *2 – 276*	5	–	–	–	–	–	–	–	–	–	–

Table 4. Percentage heart rate reserve (%HRR) for working periods, tasks (within working periods) and activities (within the 'on the spot' working period) during 24-h shifts. The table shows the number of 24-h shifts that were used for the calculations (#) in each case. Working periods, tasks and activities are sorted from high (above) to low (below) %HRR

%HRR working periods			%HRR tasks (within the 'working on the spot' working period)			%HRR activities (within the 'working on the spot' working period)		
	M (SD), *Range*	*n*		M (SD), *Range*	*n*		M (SD), *Range*	*n*
Working on the spot	30.6 (8.5), *4.0–48.5*	52	SCBA tasks	58.4 (19.1), *30.3–92.0*	20	Walking on stairs	43.9 (17.2), *14.1–86.1*	20
From alarm to turn out	26.4 (9.8), *3.7–55.6*	53	Inside	43.4 (18.6), *12.3–74.8*	13	Climbing	43.7 (20.3), *42.0–91.7*	5
			Water-collection	37.7 (15.0), *19.8–83.4*	11	Lifting/carrying	38.4 (12.6), *3.1–58.7*	35
			Preparation	32.1 (10.3), *5.0–53.6*	49	Other activities	38.0 (15.3), *5.6–61.8*	22
			Extinguish	31.9 (8.9), *19.8–83.4*	11	Running	37.9 (16.6), *4.6–66.0*	14
						Stooping	36.8 (14.7), *6.6–72.1*	31
						Pulling/dragging	35.6 (16.2), *12.3–77.4*	22
						Pushing	30.9 (11.5), *25.0–61.5*	7
						Kneeling/squatting	24.6 (16.0), *3.8–55.2*	5

4. Discussion

The results of this study indicate that actual fire-fighting in The Netherlands is characterised by a low number of incidents (mean: 1.5/24-h shift) and short durations of 'turn-out' time (mean: 88 min, SD: 76 min), tasks and activities during 24-h shifts. In the literature many studies stress that fire-fighting is a job that makes extreme physical demands. This conclusion is predominantly based on high heart rates measured during simulated fire-fighting activities (Barnard and Duncan 1975, Kuorinka and Korhonen 1981, Puterbaugh and Lawyer 1983, Louhevaara *et al.* 1985, O'Connell *et al.* 1986, Misner *et al.* 1987, Romet and Frim 1987, Sothmann *et al.* 1991, Gledhill and Jamnik 1992, Gilman and Davis 1993, Lusa *et al.* 1993, Bennett *et al.* 1995, Smith *et al.* 1996, 1997, 1998, 2001, Carter *et al.* 1999, Williford *et al.* 1999, Oldham *et al.* 2000, Petersen *et al.* 2000). The present study indicates that, over a 24-h shift, the energetic intensity for actual fire-fighting is moderate. There is no prolonged high energetic work and peak loads are of short duration and occur incidentally. After considering the %HRR values and the corresponding duration of the observed tasks and activities, the most physically demanding tasks and activities, in terms of duration, frequency and intensity during 24-h shifts are the 'Inside and SCBA tasks' and 'Water collection', and activities like lifting and stooping. For activities the %HRR was also chosen as a measure for the energetic workload, but it is important to realise that the static component of the muscular performance of physical activities, such as lifting and pulling, may partly explain the high heart rates during these activities (Garcin *et al.* 1996). Only one study (Sothmann *et al.* 1992) found a mean %VO2max of 63 during 15 min of actual fire-fighting. This finding is comparable with the mean %HRR of 58 for SCBA tasks during 12 min of actual fire-fighting which was found in the present study. For incidents the mean %HRR during the 'on the spot' period was 30.6 with a corresponding duration of 58 min. The task 'diving', which has been reported in the literature as the most physically stressful task in fire fighting (82%VO2max during simulated diving tasks; Van Ooij 1998), did not occur during the incidents in the present study.

Only the short-duration 'Inside and SCBA' tasks exceeded the energetic guideline of Wu and Wang (2001, 2002) on the basis of the 90th percentile value of the real duration of these tasks. To the best of the authors' knowledge, no other studies have used acceptable workload limits in a similar way to explore the development of excessive fatigue during actual fire-fighting. Previous studies suggest that 33% and 50% of the individual VO2max should be the acceptable workloads for general 8-h and 1-h physical work respectively (Saha 1979, Kemper *et al.* 1990). The energetic workload guideline of Wu and Wang (2001, 2002) was used in the present study because it was more appropriate for calculating the exact value of the MAWD for the values of the %HRR and the corresponding duration of (short and long) working periods, tasks and activities. Furthermore, excessive fatigue, which is identified as related to fire-fighting in the present study, might be related to the development of musculoskeletal and other health complaints. However, there is no evidence based on longitudinal epidemiological studies for a cut-off point which predicts the development of these complaints, using the aforementioned limits for acceptable workload.

Despite the incidental peak loads, it is likely that fire-fighters have sufficient recovery time during a 24-h shift. Apparently, high intensity exercise could have positive effects on fitness and health (Åstrand and Rodahl 1986). Other factors might influence the relationship between the work demands in actual fire-fighting and the reported occurrence of accidents, high levels of musculoskeletal symptoms, health complaints and sudden deaths among fire-fighters (Orris *et al*. 1995).

First, the dangerous and unsafe environments during emergency incidents in actual fire-fighting may go a long way to explaining the occurrence of accidents. For example, many accidents occur on the emergency vehicles. The most dangerous positions on a fire engine are the rear step and the running board (Matticks *et al*. 1992).

Second, the development of injuries and/or musculoskeletal complaints can be explained by exposure to other physical activities such as soccer and gymnastics during working time. Furthermore, although the present study focuses mainly on the assessment of energetic workload, the duration of activities such as lifting and stooping during 24-h shifts gives an indication of the biomechanical load. As fire-fighting activities are performed quickly, rapid and extreme movements of the torso may create biomechanical overload. Even if the rate of lifting in the fire service is not high, the loads (for example victims) can be very high. Although the intensity of the lifted loads was not measured objectively in the present study, it is to expected that the loads lifted by a single fire-fighter often exceed the NIOSH limit of 25 kg (Waters *et al*. 1993). As an example, some studies estimated compression of the back on the basis of externally exerted force during frequently performed rescue tasks, such as lifting a power-saw (Lusa *et al*. 1991) and carrying off patients on a stretcher (Lavender *et al*. 2000a,b). The possible individual biomechanical overload during actual fire-fighting and the consequent development of complaints might be explored further.

Third, some explanations can be offered for the development of other complaints. The high cardiovascular strain and the possible deleterious effects of carbon monoxide and other fire contaminants place the fire-fighter at an increased risk of cardiovascular disease (Matticks *et al*. 1992, Melius 1995). Though the increased use of protective equipment may reduce exposure to toxic fire contaminants, it can also increase physical stress (Louhevaara *et al*. 1985, 1995, White *et al*. 1989, Lusa *et al*. 1993).

Fourth, the energetic peak loads during actual fire-fighting could trigger sudden cardiac death (Mittleman *et al*. 1993, Jensen-Urstad 1995, Franklin *et al*. 1997, Claessens *et al*. 2000). It should be noted that the risk of sudden death during physical activity is extremely low for individuals without known heart disease who exercise regularly (Jensen-Urstad 1995). However, it is conceivable that subjects with a decreased capacity and/or with undiagnosed heart conditions ('subjects at risk') run a greater risk of sudden death during the peak loads in fire-fighting. Personal risk factors have been identified for increased mortality among fire-fighters, such as higher age, lower spirometric function, lower predicted VO2max, rising cholesterol and greater BMI (Kales *et al*. 1999). Also, blood pressure, smoking and diabetes have a clear effect on the incidence of sudden death (Algra 1990). Finally, besides the risk for individuals with heart complaints during performance of peak loads during single incidents in actual fire fighting, the repeated exposure to high intensity work over the 'active' working years of fire-fighters may also lead to cardiac problems over a long time period (Haas *et al*. 2003).

In the interests of health surveillance, the development of physical and medical selection procedures, training and workplace adjustments, attention needs to be paid to peak energetic values during tasks that might lead to excessive fatigue (Inside and SCBA). Individuals with health complaints or a high personal risk should be discouraged from undertaking such peak energetic workloads. Improvement of the ergonomics of the workstation, decreasing the weight of equipment to be handled and job rotation between team members might decrease physical workload. For individual fire-fighters, it can be suggested that they partake in fitness activities to improve cardiovascular and musculoskeletal strength and endurance to be able to meet the job demands and for prevention of developing health complaints. Physical training and the development of specific physical performance tests should be aimed at improving task-specific fitness and at an adequate performance of these energetic peak loads. Finally, it might be useful to pay more attention to the identification of biomechanical overload during actual fire-fighting with a view to preventing musculoskeletal complaints.

5. Conclusion

Although the occurrence of incidents is low and the duration of working periods, tasks and activities is short during 24-h shifts, two tasks (SCBA and Inside) in actual fire-fighting exceeded the guideline for energetic workload. The peak loads during these tasks are energetically high, which could lead to the development of excessive fatigue.

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