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Determinants of maximal oxygen uptake ($VO_{2\ max}$) in fire fighter testing

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ABSTRACT

The aim of this study was to evaluate current daily practice of aerobic capacity testing in Belgian fire fighters. The impact of personal and test-related parameters on the outcome has been evaluated.

Maximal oxygen uptake ($VO_{2\ max}$) results of 605 male fire fighters gathered between 1999 and 2010 were analysed. The maximal cardio respiratory exercise tests were performed at 22 different centres using different types of tests (tread mill or bicycle), different exercise protocols and measuring equipment.

Mean $VO_{2\ max}$ was 43.3 (SD = 9.8) ml/kg.min. Besides waist circumference and age, the type of test, the degree of performance of the test and the test centre were statistically significant determinants of maximal oxygen uptake.

Test-related parameters have to be taken into account when interpreting and comparing maximal oxygen uptake tests of fire fighters. It highlights the need for standardization of aerobic capacity testing in the medical evaluation of fire fighters.

1. Introduction

Fire fighting is a physically demanding profession even though the number of interventions and occupational demand during a 24-hour shift might be low. At an emergency scene, fire fighters perform a series of actions under stressful conditions, such as moving and lifting heavy weights and rescuing victims while wearing protective clothing and a self-contained breathing apparatus (SCBA). The total weight of the equipment and SCBA is around 21–22 kg. As such, it increases the energy demand significantly (Baker et al., 2000; Dreger et al., 2006; Selkirk and Mc Lellan, 2004).

Bos et al. (2004) conducted a field study during eighty-five 24 h shifts in Dutch fire stations and they concluded that two tasks (SCBA and Inside tasks) in actual fire fighting exceed the guideline for energetic workload of Wu and Wang (Wu and Wang, 2001, 2002). This guideline consists of prediction models on the relationship between the percentage of heart rate reserve (%HRR) and the acceptable work duration (MAWD) for both short and long periods of work. The real duration of the “Inside and SCBA” tasks were 23 and 21 min; the corresponding MAWDs are 17 and 4 min respectively. In addition, fire fighters are exposed to high temperatures, which further stresses the cardiovascular system (Barr et al., 2010; Bruce-low et al., 2007; Selkirk and Mc Lellan, 2004).

Heart rates measured during normal fire fighting tasks are at or near maximal levels (Bos et al., 2004). Elsner and Kolkhorst (2008) found the oxygen uptake associated with performing live fire rescue and suppression tasks were around 62% of the VO_{2max}. According to an investigation of Bilzon et al. (2001) metabolic demands of simulated shipboard fire fighting tasks could reach up to peaks of 43 ml oxygen/kg/min, being equivalent to 82% of VO_{2max}. Consequently, it is imperative that fire fighters are physically fit to perform their job and to guarantee their own safety as well as the safety of their colleagues and victims. Numerous studies have demonstrated the necessity of maintaining a high level of aerobic capacity for rescue personnel such as fire fighters (Bilzon et al., 2001; Bos et al., 2004; Elsner and Kolkhorst, 2008).

Leading researchers and agencies recommend that the measurement of aerobic capacity would be included in the medical examination of fire fighters. The measurement of aerobic capacity is recommended to be part of the medical examination of fire fighters by leading researchers and agencies (Ben-Ezra and Verstraete, 1988; Elsner and Kolkhorst, 2008; International Association of Fire Fighters, 2008; Peate et al., 2002). VO_{2max} is used as a measure of aerobic capacity. Investigations of fire fighting activities

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Mortality and life expectancy of professional fire fighters in Hamburg, Germany: a cohort study 1950 – 2000

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Abstract

Background: The healthy worker effect may hide adverse health effects in hazardous jobs, especially those where physical fitness is required. Fire fighters may serve as a good example because they sometimes are severely exposed to hazardous substances while on the other hand their physical fitness and their strong health surveillance by far exceeds that of comparable persons from the general population.

Methods: To study this effect a historic cohort study was conducted to assess mortality and life expectancy of professional fire fighters of the City of Hamburg, Germany. Fire departments and trade unions questioned the validity of existing studies from outside Germany because of specific differences in the professional career. No mortality study had been conducted so far in Germany and only few in Europe. Information on all active and retired fire fighters was extracted from personnel records. To assure completeness of data the cohort was restricted to all fire fighters being active on January 1, 1950 or later. Follow up of the cohort ended on June 30th 2000. Vital status was assessed by personnel records, pension fund records and the German residence registries. Mortality of fire fighters was compared to mortality of the Hamburg and German male population by means of standardized mortality ratios. Life expectancy was calculated using life table analysis. Multivariate proportional hazard models were used to assess the effect of seniority, time from first employment, and other occupational characteristics on mortality.

Results: The cohort consists of 4640 fire fighters accumulating 111796 person years. Vital status could be determined for 98.2% of the cohort. By the end of follow up 1052 person were deceased. Standardized Mortality Ratio (SMR) for the total cohort was 0.79 (95% CI, 0.74–0.84) compared to Hamburg reference data and 0.78 (95% CI, 0.74–0.83) compared to National German reference data. Conditional life expectancy of a 30 year old fire fighter was 45.3 years as compared to 42.9 year of a German male in normal population. Job tasks, rank status and early retirement negatively influenced mortality. For fire fighters with comparably short duration of employment the mortality advantage diminished with longer time since first employment. SMR of persons who retired early was 1.25 (95% CI, 1.13–1.60) in reference to the general German population and the SMR of 1.71 (1.18–2.50) in the multivariate regression model.

Conclusion: A strong healthy worker effect was observed for the cohort, which diminished with longer time since first employment for fire fighters with shorter duration of employment, as expected. The negative effects on mortality of job tasks, rank status and in particular early retirement indicate the presence of undetermined and specific risks related to occupational hazards of fire fighters.

Background

At the end of the 1990es a raise of retirement age for police and fire fighters was discussed in the German parliament in the context of reforms of social welfare system, pension fund financing. The retirement age of 60 years was supposed to be raised to 62 years. Trade unions and fire departments opposed these plans arguing that life expectancy of fire fighters was already dramatically shorter compared to general population. Arbitrarily collected and published data from fire departments indicated a low average age at death [1]. Later inquiries showed that these self-collected data were wrong.

All previously published mortality data from other countries (Table 1) indicated a lower mortality with standardized mortality ratios between 0.76 and 0.99. However, in the light of the self-collected data in Germany these studies were considered unreliable and "not applicable" by both, the fire departments and the trade unions.

In July 2000 the head of fire department of the Free and Hanseatic City of Hamburg requested the Occupational Medical Service to conduct a scientific study to answer to this question. The validity of existing studies from outside Germany was questioned by fire departments because of presumed specific differences in the professional career in Germany like frequent life long employment, work till later age, remaining a fire fighters longer because of specific German pension benefits. No mortality study had been conducted so far in Germany and very few in Europe. In collaboration with the Institute of Mathematics and Computational Sciences in Medicine of the School of Medicine at University of Hamburg a retrospective cohort study was initiated in autumn 2000.

This study reports the findings of a retrospective cohort study on the mortality of fire fighters of the Fire Department of the City of Hamburg, Germany. The objectives were to establish the life expectancy and standardized mortality ratios compared to the Hamburg and the national reference population. We put special emphasis on disentangling the suspected strong healthy worker effect in this cohort from the effects of potential chemical exposures and heavy work load.

Methods

All male fire fighters of the Fire Department of the City of Hamburg, Germany being active between January 1, 1950 and June 30, 2000 (end of follow-up) were included in the study population. They were all full-time, professional employees. The number of female fire fighters was negligible and thus they were excluded. We included only active fire fighters and no administrative personnel of the Fire Department.

Date of birth, date of death, date of employment, date of end of active duty, reason of end of active duty, duration of employment according to the type of tasks (fire fighting & rescue service vs. administration) and rank were obtained for pensioners and active fire fighters from the Hamburg Fire Department. This included e.g. card files of pensioners and the archive of personnel records.

Table 1: Published studies on mortality of fire fighters

Author	Year	City/Country	Size of Cohort	Period of recruitment	End of Observation	SMR	95% CI
Musk [30]	1978	Boston/USA	5655	1915–1975	7/1975	0.91	na
Eliopulos [31]	1984	Western Australian Fire Brigade	990	10/1939 – 12/1978	12/1978	0.80	0.67–0.96
Vena [32]	1987	Buffalo/USA	1867	1950 – 1979	1979	0.95	na
Heyer [33]	1990	Seattle/USA	2289	1/1945 – 12/1979	12/1983	0.76	0.69–0.85
Hansen [34]	1990	Denmark Census 1970	886	1970	1980	0.99	0.75–1.29
Beaumont [35]	1991	San Francisco/USA	3066	1940 – 1970	1982	0.90	0.85–0.95
Demers [9]	1992	Seattle. Tacomo. Portland/USA	4546	1944 – 1979	1989	0.81	0.77–0.86
Guidotti [11]	1993	Alberta/Canada	3328	1927 – 1987	1987	0.96	0.87–1.07
Aronson [36]	1994	Toronto/Canada	5995	1950 – 1989	1989	0.95	0.88–1.02
Tornling [37]	1994	Stockholm/Sweden	1116	1931 – 1983	1986	0.82	0.72–0.91
Deschamps [38]	1995	Paris/France	830	1973 – 1991	1991	0.52	0.35–0.75
Baris [39]	2001	Philadelphia/USA	7789	1925 – 1986		0.96	
Present study	2001	Hamburg/Germany	4557	1.1.1950-30.6.2000	6/2000	0.78	0.74–0.83

na: not available

Initially we identified a total of 4805 fire fighters who had ever worked in the Fire Department of the City of Hamburg. To ensure completeness of data sets, the cohort and due to the availability of reference mortality data we restricted analysis to fire fighters who were active on January 1, 1950 or were employed before the end of follow up on June, 30, 2000. Thus 141 persons (including 125 deceased) were not included in the cohort because they had left the department before January 1, 1950. In addition, we excluded 10 cases with missing dates of entry, 2 cases with age at employment lower than 15 years and 12 pensioners with missing dates of leaving the fire department.

The database from the personnel department was cross-checked with other data sources. By these additional data sources we added 122 persons out of the files of retired fire fighters, 149 persons out of the personnel archive paper files. We corrected 22 dates of death with databases from the retirement and inheritance fund.

Comparing the database to other publications corroborates the presumption of almost 100% completeness: the department yearbook of 1972 lists 1026 persons for 1955 compared to our 1021, for 1967: 1660 vs. 1657, for 1972: 1604 and 1625 vs. 1644.

Vital status was determined from the department's personnel records and pension fund. No information regarding causes of death was available in these data sources and no additional funding was available to ascertain this information from the death certificate registries. For 381 persons vital status remained unknown. We obtained further vital status information from the German municipal residents' registration and vital status offices. These mandatory registries capture residence and vital status of persons who e.g. moved to another city. Vital status for 77% of these 381 persons (227 living, 66 dead) was obtained. Unclear vital status and hence lost to follow-up were 88 persons.

The final cohort entering the statistical analysis thus included 4557 fire fighters with known vital status.

Standardized mortality ratios (SMR) were calculated using the Hamburg mortality rates from the Department of Statistics of the City of Hamburg and German reference rates provided by the German Cancer Research Centre, Heidelberg. SMR computations used the software SMRPER [2]. Confidence intervals were calculated assuming a Poisson distribution for the observed cases. We examined mortality in stratified analyses by year of entry, type of task, rank group (rank), duration of employment and time since first employment (duration of observation).

Life expectancy for different ages at entry into the fire department were calculated by life table analysis according to the Manual of Mortality Analysis [3] using the time period and age specific death rates of the cohort. Comparable life expectancies for the Hamburg and German population were computed from weighted death rates of Hamburg and Germany. Weights were computed by age- and date-of birth-specific numbers of fire fighters.

Multivariate subgroup analyses were conducted with time dependent proportional hazard models using rank group, age at follow up, year of first and duration of employment as predictors. The analyses were performed with SPSS. For the purpose of analysing work time-related effects, only persons born January 1, 1950 or later were included.

Details which could have determined the exposure better besides the classification into "fire fighting & rescue" vs. "administrative" groups were not available. Further classification for a more elaborate job-exposure matrix (for example: position in the team while fire fighting) was considered inappropriate and not reliable. The reasons for this decision were:

a) Professional fire fighters in Germany rotate almost on weekly – if not daily – base into different positions in the team.

b) Major fires with very high exposures are rare. In Hamburg major structural and industrial fires occur with a sequence of one to two per year for each fire fighter.

c) High exposures (for example, from carcinogenic chemicals such as diesel fumes) occur during maintenance and routine work in the station.

d) Even when major fires occur it is unclear who in the brigade has actually the highest exposure. The attack team have also the highest level of personal protection (SCBA); two attack teams (on ground and on ladder) might have completely different exposure levels; the commander who tries to get a good glimpse on the situation but doesn't use his mask in order to be able to communicate better via walkie-talkie might even have the higher exposure to burn products and fumes. It is known that the highest exposures are often during overhaul and destruction, so the position of the fire fighter during the actual fire is not predictive of his/her exposure during the entire course of the sortie.

e) Even if a position or task could have been documented the use of SCBA is unknown.

Results

The final cohort entering the statistical analysis thus comprised 4557 persons: 2169 (47.6%) active fire fighters and 2388 (52.4%) pensioners. During follow up 1052 deaths were observed.

Table 2 shows the descriptive statistics for the cohort. Half of the included persons were employed before 1966 and half left the fire brigade before 1985. Half of the workers have a maximum duration of employment of 18 years.

Reasons for leaving active duty

Regular retirement was the reason for 1419 fire fighters (59.4%) and early retirement for 470 (19.7%). A total of 237 fire fighters (9.9%) asked to leave, 214 fire fighters (9.0%) died before retirement. For 48 fire fighters (2.0%) we could not determine their reasons to leave active duty in the department.

Life expectancy

Life expectancies for fire fighters in comparison to male persons from the German and Hamburg population according to different ages at employment are shown in Table 3. The life expectancy of a fire fighter aged 20–24 year at entry was 54.9 years, 2.7 and 2.8 years more in comparison to the German or Hamburg reference respectively. For a fire fighter aged 30–34 the advantage in life expectancy was 2.2 years compared to Hamburg and 2.4 years compared to Germany.

Standardized Mortality Ratios

Overall SMR using the age specific death rates of Hamburg and Germany were notably reduced (Table 4). SMR for the cohort was 0.79 with a 95% CI of 0.74–0.84 (Reference Hamburg) and 0.78 with a 95% CI of 0.74–0.83 (Reference Germany)). Because the results of the SMR computation were similar for both reference populations the subgroup analysis given below only refers to the German population.

Stratification by year of entry shows a reduction in mortality over time. For persons who were already active on the 1/1/1950 the SMR was 0.85 (95% CI, 0.79–0.91). For fire fighters who were employed between 1950 and 1954 the SMR was 0.66 (95% CI, 0.49–0.88), decreasing to 0.47 (95% CI, 0.31–0.68) for the last stratum (entry 1970–2000). A further stratification of year of entry by type of duties (fire fighting & rescue service) yielded a similar trend in the SMRs (data not shown).

Table 2: Descriptive statistics for the fire fighter cohort

Variable	Median	Minimum	Maximum
Date of birth	1942	1885	1980
Date on entry	1966	1950	2000
Date of leaving	1985	1950	2000
Date of death	1981	1950	2000
Age at employment	26	15	65
Age at end of observation	55	20	103
Duration of employment	18	0.02	47

More detailed analysis on SMR in sub-groups is given in Table 5. All time- and age-related variables were analysed independently. Multivariate analysis is discussed below.

Mortality declines the later the year of employment. SMR changes from 0.85 (95% CI, 0.79–0.91) for persons employed at 1/1/1950 to 0.47 (95% CI 0.31–0.68) for fire fighters who joined between 1970 and 2000 (Table 5).

For persons with available data for the type of tasks (N = 4470) differences in mortality were observed: fire fighters who spent more than 50% of their working time in the fire fighting & rescue service showed a higher SMR (0.79; 95% CI, 0.74–0.84) than fire fighters with more than 50% of their working time in the administration (SMR, 0.53; 95% CI, 0.35–0.78). Categorizing the cohort in two subgroups who had worked exclusively in the fire fighting & rescue service or in the administration as fire fighters yielded SMRs of 0.81 (95% CI, 0.75–0.87) and 0.43 (95% CI, 0.12–1.10), respectively (data not shown).

Dividing the cohort into 'rank groups' according to the German state employment categories (in German: "mittlerer, gehobener und höherer Dienst") as indicators of socio-economic status showed higher mortality (SMR, 0.82; 95% CI, 0.77–0.87) for the 'middle rank' than for fire fighters in the 'high' or 'higher rank' group combined (SMR, 0.51; 95% CI, 0.41–0.63) with 4309 available data sets (Table 5). The 'middle rank' is the lowest income group a fire fighter can join in the last decades. The terminology has historical reasons: the "low rank" category was abandoned in the middle of last century. Depending on prior qualification fire fighters can join the higher rank groups directly. For 248 persons reliable information on rank was not available.

Regarding the 'reason of retirement' persons with a regular retirement showed a reduction in mortality (SMR, 0.79; 95% CI, 0.73–0.85) compared to the German reference population (Table 5). Fire fighters who left the department because of other reasons showed an increase in mortality: early pensioners (SMR, 1.35; 95% CI, 1.13–1.60) left the department for health reasons and other fire fighters who left the fire department on their own request (SMR, 1.12; 95% CI, 0.77–1.57) for instance to move to a different city.

Table 6 shows the result of the SMR calculations for duration of and time since first employment simultaneously.

Table 3: Age specific life expectancies for fire fighters in comparison to Hamburg and Germany reference population

Age Group	Fire Fighters Cohort Hamburg	Germany Reference	Difference to German Reference	Hamburg Reference	Difference to Hamburg Reference
20–24	54.9	52.2	2.7	52.1	2.8
25–29	50.2	47.6	2.6	47.8	2.4
30–34	45.3	42.9	2.4	43	2.2
35–39	40.4	38.2	2.2	38.4	2.1
40–44	35.7	33.5	2.2	33.7	2
45–49	31.1	29	2.1	29.3	1.8
50–54	26.7	24.7	1.9	25	1.6
55–59	22.5	20.6	1.8	21	1.5
60–64	18.4	16.8	1.6	17.3	1.2
65–69	14.4	13.4	1	13.8	0.6
70–74	11	10.4	0.7	10.8	0.3
75–79	8.4	7.8	0.6	8.2	0.2
80–84	6.4	5.7	0.7	6	0.3
85–89	4.7	3.9	0.9	4.1	0.6

The SMR in the first five years after joining the fire fighters was only 0.3 (0.12–0.61). This decreased mortality seemed to disappear for the subgroups of fire fighters with a total duration of employment of less than 10 years, however, numbers in these subgroups were quite small. For the subgroups with longer duration of employment the mortality appeared to increase with longer period of follow up, but after 30 years of observation the SMR continued to be significantly below 1.

Multivariate subgroup analysis with proportional hazard models

To include time dependent covariates a subgroup was formed excluding all workers already active on the 1/1/1950. Table 7 presents the results of the proportional hazard model (N = 3576) using following time dependent covariates: duration of employment, year of employment, age at employment, rank group, reason for leaving simultaneously. Adding the variable 'type of task' into the model did not improve it. It was hence not included.

Duration of employment

A longer duration of employment (more than 20 years) in comparison to the reference group '0–5 years duration of employment' is associated with a lower mortality risk (20–30 years RR, 0.35; 95% CI, 0.20–0.62; and > = 30 years RR, 0.42; 95% CI, 0.23–0.75). A duration of employment of 5–10 years seems to be connected with increased risk (RR, 2.43 95% CI, 0.93–6.34) but it includes a large statistical uncertainty. We also computed the effect of duration of employment as a continuous covariate in this model and found a RR of 0.73 (95% CI, 0.61–0.87) for each 10 years of employment (result not shown in Table 7).

Year of entry

A later date of entry is associated with a lower mortality risk. In comparison to the reference group 'entry between 1950–1954' the mortality risk for the group 'entry after 1970' is reduced to 46 % (RR, 0.46; 95% CI, 0.14–1.57).

Age at entry

The age of entry had been categorised in 3 groups. In comparison to the reference group 'age 15–25 years' the mortality of the group 25–30 years reveals no difference. An increased relative risk has been observed for the workers with an age at entry higher than 30 years (RR, 2.38; 95% CI, 1.36–4.15).

Rank group

A lower risk was found for the group of the high and highest rank group combined in comparison to the middle rank group (RR, 0.39; 95% CI, 0.24–0.62).

Early retirement

Workers who leave the fire department due to early retirement have an increased relative risk (RR, 1.71; 95% CI, 1.18–2.50) in comparison to all others.

Table 4: Standardized mortality ratios compared to Hamburg and German Reference Population

	N	*Observed*	*Expected*	*Person years*	*SMR*	*95% CI*
Reference Hamburg	4557	1052	1331	111795.7	0.79	0.74–0.84
Reference Germany	4557	1052	1345.3	111795.7	0.78	0.74–0.83

Table 5: Standardized mortality ratios by risk factors

	N	Observed	Expected	Person years	SMR	95% CI
Year of employment	4557					
Employed on 1. Jan 1950	981	802	943.7	31702.2	0.85	0.79–0.91
1950–1954	125	47	71.5	5334.6	0.66	0.49–0.88
1955–1959	408	82	122	16300.8	0.67	0.54–0.83
1960–1964	384	50	74.8	13926.4	0.67	0.50–0.88
1965–1969	428	43	73.7	14109.8	0.58	0.42–0.79
1970–2000	2231	28	59.6	30421.9	0.47	0.31–0.68
Predominant type of tasks	4470					
Fire fighting and rescue service	4116	972	1237.2	104685.4	0.79	0.74–0.84
Administrative jobs as fire fighter	354	26	49	5087.8	0.53	0.35–0.78
Rank groups	4309					
Middle ranks [see note]	3631	900	1101	89142.8	0.82	0.77–0.87
High ranks	632	72	150.2	18172.4	0.48	0.38–0.60
Higher ranks	46	14	17.3	1243.9	0.81	0.44–1.36
Combined: high and higher ranks	678	86	167.5	19416.3	0.51	0.41–0.63
Reasons for leaving	2124					
Own request	236	33	29.5	4033.1	1.12	0.77–1.57
Early retirement	469	131	96.9	4989.6	1.35	1.13–1.60
Regular retirement	1419	644	816.2	16409.8	0.79	0.73–0.85

Note: Reference for the calculations is the German general population. The "middle rank" is actually the lowest group a fire fighter can join.

Discussion

This paper reports on the first cohort study undertaken in Germany to examine the mortality of fire fighters with its typical, quasi lifelong employment of professional fire fighters. We are confident that the cohort of fire fighters is complete for the time period after 1950. It constitutes the largest cohort study of fire fighters' mortality in a European country.

The study was limited by the fact that we could not collect a detailed exposure history of fire fighters and data on causes of death.

Taking runs as a proxy parameter for exposure is not established as standard in the research on fire fighter risks. The differences in job tasks, wind direction or protective equipment on jobs at the same fire do not allow taking number of runs as proxy. The exposure matrix of fire fighters is highly complex as time at fire does not indicate that for example protective equipment was worn or not [28].

Neither the evaluation of causes of deaths nor the inclusion a control group such as officers from the Hamburg Police Department was funded by the Fire Department. We tried to account for this limitation by using the Cox

Table 6: SMRs, by duration of employment and time since first employment

Duration of observation / ***Duration of employment***	***0–4 years***	***5–9 years***	***10–19 years***	***20–29 years***	***30+ years***	***Total***
0–4 years	0.3 (7/23.6) 0.12–0.61	4.76 (4/0.8) 1.30–12.19	0.5 (1/1.9) 0.01–2.93	1.24 (4/3.2) 0.34–3.20	1.66 (10/6.0) 0.80–3.07	0.73 (26/35.5) 0.80–1.07
5–9 years		0.51 (12/23.7) 0.26–0.88	1.04 (3/2.9) 0.21–3.04	0.59 (2/3.39) 0.07–2.13	3.62 (4/1.1) 0.99–9.31	0.68 (21/31.1) 0.42–1.03
10–19 years			0.60 (37/61.6) 0.42–0.83	1.5 (11/7.3) 0.75–2.70	0.76 (9/11.8) 0.35–1.45	0.71 (57/80.7) 0.53–0.92
20–29 years				0.60 (55/91.5) 0.45–0.78	0.67 (20/29.9) 0.41–1.03	0.62 (75/121.4) 0.49–0.77
30+ years					0.55 (71/129.5) 0.43–0.69	0.55 (71/129.5) 0.43–0.69
Total	0.3 (7/23.6) 0.12–0.61	0.65 (16/24.54) 0.37–1.06	0.62 (41/66.38) 0.44–0.84	0.68 (72/105.4) 0.53–0.86	0.64 (114/178.3) 0.53–0.77	0.63 (250/398.2) 0.55–0.71

Note: fire fighter cohort employed after 1/1/1950 (SMR, # of observed/expected cases, 95% CI)

Table 7: Multivariate Subgroup Analysis

Covariates	Relative risk (95%CI)
Rank group	
(reference "middle rank")	
High and higher rank	0.39 (0.24–0.62)
Age at employment	
(reference 15–25 years)	
25–29 years	0.91 (0.66–1.26)
> = 30 years	2.38 (1.36–4.15)
Year of employment	
(reference 1950–54)	
1955–1959	0.98 (0.56–1.71)
1960–1964	0.77 (0.37–1.58)
1965–1969	0.57 (0.25–1.27)
1970–2000	0.46 (0.14–1.57)
Duration of employment	
(reference 0–5 years)	
5–<10 years	2.43 (0.93–6.34)
10–<20 years	0.89 (0.46–1.74)
20–<30 years	0.35 (0.20–0.62)
> = 30 years	0.42 (0.23–0.75)
Early retirement	
(reference all others)	
Early retirees	1.71 (1.18–2.50)

regression model with internal comparison groups to make the effects of different risk factors inherent to the occupation visible.

Overall mortality

Our results show that the mortality of the fire fighter cohort of Hamburg is about 20% lower than the mortality of the reference population. They confirm findings from most of the other published studies from different countries (Table 1). However, our findings are in the lower range of previously published studies. It might indicate that the selection processes and the intensive medical surveillance programs in Germany have a greater effect than the programs in other countries with lower standards (see discussion below).

The lower mortality of fire fighters in comparison to the general population is probably influenced by the healthy worker effect in several aspects. The question how much the healthy worker effect masks a potentially negative effect of occupation on mortality arises in all occupational cohort mortality studies [4,5]. The reference to 'general population' is convenient and – as it was the case here – often the only financially feasible way. Unfortunately it is not the best comparison group to determine the occupation-induced mortality risks because of the selection of cohort members based on health status and risk factors at the beginning of work.

Using definitions according to Choi [6], several components of the healthy worker effect (HWE), e.g. the healthy hired, low-risk hired, worker healthier and the healthy worker survivor effect probably led the observed low mortality. In general the magnitude of the healthy worker effect is estimated to be around 20% advantage in mortality (see [4] for further discussion). Our result (SMR of 0.78) is very similar to that.

We observed a decline of the healthy worker effect with increasing time since first employment. This effect was more pronounced for the subgroups with a total duration of employment of less than ten years. This observation is consistent with the assumption that the "healthy hired" component disappears within this time frame from date of first employment. For fire fighters with longer duration of employment (10–29 years) the mortality advantage is also declining, but the SMR does not increase to 1. This may probably reflect a levelling off of the "low-risk-hiring" component. Finally, the SMR for the subgroup with working time durations of more than 30 years was 0.55 (95% CI, 0.43–0.69), i.e. lower than those for the other subgroups with shorter duration but the same time since first employment. This indicates a pronounced long term effect of the "work healthier" and the "healthy survivor" component of the healthy worker effect.

Physical and medical fitness for professional and voluntary fire fighters is required nationwide in Germany using common standards. This constitutes a major difference to the US American system where regular physical performance tests are suggested by National Fire Protection Association (NFPA)/USA [7] but not regularly required on national level [8]. However, on state and/or community level in the USA regular physical performance tests are sometimes mandatory.

The stringent selection process in Germany demands physical and psychological health and fitness. After joining there are regular and intensive medical examinations: until the age of 50 every 3 years, beyond 50 every year. These tests include stress-ECG to evaluate standardized physical fitness and a fitness test with heavy respiratory protection gear on the obstacle course. In the stress-ECG fire fighters below 30 years of age have to perform at an energy level of three Watt per kilogram of bodyweight. Fire fighters above 30 years of age have to show the same level of performance reduced by one percent per year of age above 30 years. The capacity to perform at an energy level of 200 Watt minimum has to be proven at all occasions. In addition to the fitness test, other medical criteria for vision test, audiometry, lung function test and acceptable blood pressure response and heart rates at stress-ECG have to be met.

The clearance to wear protective gear i.e. the permission to serve in the brigade is cancelled once the fitness tests are failed. Also fire fighters in mostly administrative duty keep themselves fit and pass the medical endurance tests as they might have to go out on the scene in major emergencies. Only these were included in the comparison between 'fire fighting' vs. 'administrative duty' and show a definite impact of fire fighting tasks on mortality.

The professional fire fighters in Hamburg and mostly all over Germany are civil servants (German: 'Beamte'). This includes remarkable social benefits. Very few leave the department once they joined; almost all have lifelong careers in the fire departments. Hence, fire fighters over 55 years are still in active duty at the scenes. Hence the passion, when the political discussion to raise the retirement age to 65 years started.

The lower overall mortality does not indicate, however, that there were no other specific causes of death which increased the risk of death of fire fighters. A case-control study in the USA on on-duty deaths of active fire fighters has shown increased risks of death by coronary heart disease during fire suppression (OR = 64.1, 95% CI 7.4–556); training (OR = 7.6, 95% CI 1.8–31.3) and alarm response (OR = 5.6, 95% CI 1.1–28.8). The rate of on-duty deaths caused by coronary heart disease is reportedly higher than in other comparable occupational groups such as police or emergency services [8]. Other specific causes of deaths with higher than normal mortality in fire fighters are reported such as certain kinds of brain or colon cancer, leukemia, kidney and urethra cancer, prostate and bladder cancer [9-12].

Mortality of early retirees

Our study confirms findings that showed an elevated SMR for persons who retire early. We observed a SMR of 1.35 (95% CI, 1.13–1.60) in reference to the general German population and a SMR of 1.71 (95% CI, 1.18–2.50) in the Cox-Regression in reference to all others. We did not observe any beneficial effect of early retirement as documented in a Danish study [13] and the Whitehall II study on effects of normal retirement. [14].

In a Danish population-based study the disability benefit recipients showed were markedly elevated mortality [15]. Retirement in itself seems to be a risk factor for early death. In a British study men who were unemployed had a RR of 2.13 (95% CI, 1.71–2.65, men who retired early for reasons other than illness had still a significantly higher mortality compared with employed men (RR 1.87, 95% CI, 1.35–2.60) [16].

A study of past employees of Shell Oil, USA, showed a significantly higher mortality of employees who retired early at 55 and who were still alive at 65 (n = 839) had a significantly higher mortality than those who retired at 65 (n = 900) (hazard ratio 1.37; 95% CI, 1.09–1.73). Mortality was significantly higher for subjects in the first ten years after retirement at 55 compared with those who continued working (1.89; 95% CI, 1.58–2.27). The significant difference, however, showed only after adjusting to sex, calendar year of entry to the study, and socioeconomic status. Retired employees in the low socioeconomic category had a higher mortality than retirees in the high category (1.17, 95% CI, 1.01–1.36) [17].

Results from the British Regional Heart Study indicated that men who retired early for reasons other than illness had a significantly increased risk of mortality compared with men who remained continuously employed (relative risk 1.87 (95% CI, 1.35–2.60)). [18] Early retirement was associated with higher mortality in a construction workers cohort in Germany (RR, 1.50; 95% CI, 1.20–1.88) [19].

Reasons for retirement, reasons for non-fitness and possible risk factors for higher mortality of retirees

Our study was limited by the fact that we could not include common risk factors for elevated mortality such as cardiovascular risk factors (e.g. blood pressure, lipid profile [20]), psychosocial risk factors (e.g. stress, life event impact, traumatic experiences, depressive disorders [21-23]) or exposure factors to toxic gases (e.g. carbon monoxide). The social medicine department which handles the retirement cases of the City of Hamburg does neither publish nor hand out detailed statistics on reasons for retirement of public employees despite multiple requests.

However, we can presume that 'reasons for early retirement' were almost identical to 'reasons for restriction of fitness' because of medical problems during active duty. From studies of the occupational health service of the Fire Department we know that the reasons for restricted fitness because of medical problems, both temporary or permanent, were cardio-vascular diseases in 39% of all cases (N = 230) and 44% in fire fighters over 50 years (N = 132), musculoskeletal diseases (25% and. 21%), respiratory disorders (5% and 6%), injuries & surgeries (9% and 5%), metabolic disorders (3% and 5%) and psychiatric disorders including addiction and abuse (6% and 5%) [24]. High blood pressure accounted only for 5% of the medical fitness restrictions but was prevalent in 20% and 23% of the unfit fire fighters.

This pattern of diseases in events of non-fitness is distinctly different from reasons for retirement because of ill health in an analysis of retirees from the National Health Service, United Kingdom, which listed musculoskeletal (49%), psychiatric (20%), and cardiovascular conditions (11%) as most common reasons [25].

The rate of high blood pressure in Hamburg fire fighters is consistent with findings from other studies which reported a prevalence of high blood pressure between 20% and 23%, the majority of the men were untreated [26].

Unspecified risk factors

Despite the pronounced healthy worker effect, our study yields several results of subgroup SMR and Cox-regression analyses which support the assumption that occupational hazards in fire fighting, which are not specified here such as stress, raised the mortality.

First, the SMR of fire fighters who worked more than 50% of their time in administrative units 0.53 (95% CI, 0.35–0.78) is lower than the mortality of persons who worked more than 50% in active fire fighting with 0.79 (95% CI, 0.74–0.84). Second, we observed a striking difference in mortality between rank groups. This confirms results of studies which show a reduced mortality in higher socioeconomic groups [27]. However, this difference could also reflect different tasks and job exposure profiles. Higher ranks are usually not part of the attack or rescue teams. Third, causes for early retirement are partly diseases often caused or triggered by the job. The elevated SMR for those persons may reflect individual susceptibility in combination with or reaction to special hazards from the job.

We are unable to forward any explanation for the rise of SMR in the group 5 to 10 years of duration of employment. As causes and circumstances of death could not be included in this study, a discussion of reasons for this finding was considered speculative by the authors.

The decreasing mortality with later date of entry is indicative of major changes in the work environment during the study period. Tactics and safety equipment for fire fighters were improved. Accident rates fell due to better techniques and safety equipment. Especially the widespread introduction of heavy respiratory protection equipment in the 80'ties lowered the exposure to fumes and gases drastically. In Hamburg respiratory protective gear was already used end of the 70'ties. [28] On the other hand, during the study period changes have occurred which may have influenced mortality negatively e.g. plastics were introduced *en mass* into the household environment and hence became part of structural fires resulting in toxic and carcinogenic burn products.

The multivariate analysis showed a considerably higher relative risk for fire fighters who joined the department after 30 years of age (SMR, 2.38). For this result we are also unable to provide any reasonable explanation as it is in contrast to findings of other studies [29]. In the absence of other explanations and due to the low numbers it could be a chance finding.

Conclusion

In summary, we could confirm in our German study the results of previous studies of a lower-than-normal mortality of fire fighters. As expected, a strong healthy worker effect with all its components was observed. The findings also suggest that the intensive medical surveillance is beneficial to the overall health and mortality of professional fire fighters.

However, results indicate negative effects of type of task, rank status and early retirement on mortality. It appears that fire fighting and rescue services have a distinct negative influence on mortality.

Abbreviations

SMR, Standardized Mortality Ratio

CI, confidence interval

RR, relative risk

HWE, healthy worker effect

SCBA, self contained breathing apparatus

NFPA, National Fire Protection Association/USA

Stress-ECG, stress-electrocardiogram

HFD, Hamburg fire department

Competing interests

The study was financially supported by the Fire Department of the City of Hamburg accounting for about 25% of the budget. None of the authors received personal remuneration from this fund. No other competing interest to declare.

Authors' contributions

NLW initiated and coordinated the study and participated together with DFJ, MP and JB in its design and result interpretation. PK and DFJ were responsible for gathering the data, data entry and quality control. Together with AK they carried out the statistical analysis. NLW, DFJ and PK wrote the manuscript. TO provided information on reasons of non-fitness and helped revise the discussion. All authors read and approved the final version.

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have led to minimal requirements for VO_{2max}, ranging from 33.5 ml/kg/min (Sothmann et al., 1990) to 41 (Bilzon et al., 2001) and 45 (Gledhill and Jamnik, 1992) ml/kg/min. In Belgium, for example, fire fighters wearing SCBA should have a minimum VO_{2max} of 45 ml/kg.min (Kiss et al., 2010).

Aerobic capacity can be measured at either sub maximal or maximal level. Sub maximal aerobic capacity tests, when properly validated, provide an accurate estimation of an individual's oxygen consumption. These tests are less expensive and easier to carry out than maximal tests since they can be performed in a fitness centre by qualified trainers or coaches. Maximal aerobic capacity tests on the other hand, can only be carried out by qualified medical personnel under the supervision of a physician. Testing must be conducted in a medical setting with electrocardiogram (ECG) monitoring, resuscitation and defibrillation equipment on site (International association of Fire Fighters, 2008). However, maximal testing is often preferred because the results are more precise and consistent than sub maximal testing (Dreger et al., 2006; Elsner and Kolkhorst, 2008; Kiss et al., 2010).

A variety of exercise tests can be used in order to determine $VO_{2\ max}$. Several studies emphasize the use of task specific exercise tests because of particular adaptations in the organism to that activity (Ben-Ezra and Verstraete, 1988; Wisløff and Helgerud, 1998). For fire fighters a tread mill or stair mill exercise test is recommended (Ben-Ezra and Verstraete, 1988; International Association of Fire Fighters, 2008). This type of exercise resembles most of the emergency activities of fire fighters. In the case of a maximal test, subjects should complete a continuous, incremental stair mill or tread mill run to exhaustion with continuous monitoring of ECG and oxygen consumption (VO_{2max}).

However, in daily practice many aerobic capacity tests are performed by cardiologists who prefer bicycle ergo meter tests because the electrocardiogram during these tests is more stable and hence shows better ischemic changes than an electrocardiogram during a tread mill test. Treadmill tests are more performed at Sports Medicine centres.

Maximal oxygen consumption depends on age, gender, physical activity, heart rate at maximal exercise, and weight (Fleg et al., 2005; Hawkins and Wiswell, 2003; Kiss et al., 2010; Laukkanen et al., 2009). Furthermore, non-personal factors like the type of test and test centre might influence an individuals' VO_{2max} (Ben-Ezra and Verstraete, 1988; Wisløff and Helgerud, 1998). As the decision to declare a fire fighter fit for his job depends largely on the result of the VO_{2max}, it is important to investigate the relation between $VO_{2\ max}$, the type of test and the possible influence of the test centre on the outcome.

The purpose of this study was to evaluate the current daily practice of aerobic capacity testing in Belgian fire fighters using data gathered from different field practitioners in different test centres.

It was hypothesized that persons who performed a treadmill test reached a higher $VO_{2\ max}$ than those who performed a bicycle test. During running more muscle groups are involved than during cycling, therefore it can be expected that $VO_{2\ max}$ is higher in tread mill running than in ergometer cycling (Wasserman and Hanssen, 2005). The second hypothesis was that the maximal oxygen uptake varied among the test centres. Test centres use different testing protocols and although it is asked to perform maximal exercise test, centres can differ in the evaluation of maximal exhaustion.

2. Study population and methods

Maximal oxygen uptake ($VO_{2\ max}$) is used for the evaluation of cardio respiratory fitness in Belgian fire fighters. Once a year, fire fighters have a medical examination by their occupational physician. Every five years, the occupational physician refers the fire fighters to a cardiologic or Sports Medicine centre for $VO_{2\ max}$ determination. According to the Belgian guidelines for the medical evaluation of fire fighters, $VO_{2\ max}$ needs to be measured directly, preferably during a maximal stair mill test, if not available during a maximal treadmill test or bicycle ergo meter test.

Since 1999, five occupational physicians of IDEWE, the largest external service for prevention and protection at work in Belgium, gathered 613 $VO_{2\ max}$ results of 605 male and 8 female fire fighters. The tests were performed at 22 different cardiologic or Sports Medicine centres.

Besides $VO_{2\ max}$, age, gender, body mass index (BMI), waist circumference, type of test (treadmill or bicycle) and medical centre, data on the quality of the performance of the tests such as heart rate at maximal exercise were registered. Maximal oxygen uptake was directly measured during a maximal cardio respiratory exercise test on a treadmill or bicycle ergo meter. As fire fighters were referred to different cardiologic or Sports Medicine centres, different test protocols and measuring equipment were used. The comparison of the heart rate at maximal exercise to the expected maximum heart rate for age (220 beats per minute (bpm) − age) was used as a measure of the quality of the performance of the test (Maximum heart rate percentage = Percentage of maximum heart rate for age at maximal exercise = heart rate at maximal exercise*100/expected maximal heart rate for age).

Since there were only 8 women in the total population, the analysis was confined to the results of 605 male fire fighters who underwent cardio respiratory testing in 22 different cardiologic or Sports Medicine centres in Flanders (the Dutch speaking part of Belgium) from 1999 until 2010.

All statistical analyses were conducted with SPSS 19.0 for Mc Intosh. Analysis of Variance (ANOVA) was used to test for statistically significant differences in continuous variables, chi-square for dichotomous variables. A univariate general linear model was used to detect the determinants and possible interactions that best predicted maximal oxygen uptake. For this model the database was limited to the 6 cardiologic centres that delivered a minimum of 10 cardio respiratory tests, reducing the study population to 564 cases. All important factors and covariates and all their possible interactions were put in the initial model, leaving out one by one the least significant to obtain a model that best predicted the dependent variable.

3. Results

Mean age of the study population was 40.4 years ($n = 603$, SD = 11.5), ranging between 20 and 60 years. Almost 60 percent was under 45 years of age. Mean $VO_{2\ max}$ was 43.3 ml/kg.min ($n = 605$, SD = 9.8). Mean $VO_{2\ max}$ according to age, BMI, waist circumference, type of exercise test and maximum heart rate for age (220 bpm − age) attained or not attained according to age is shown in Table 1. Maximal oxygen uptake was statistically significantly dependent of all these variables.

Of the 605 tests performed, 71.1% were treadmill tests, and 28.6% were bicycle tests (for two persons the type of test was unknown). Mean maximal oxygen uptake, age, BMI, waist circumference, and percentage of the maximum heart rate for age at maximal exercise for treadmill and bicycle tests are shown in Table 2. Mean maximal oxygen uptake was statistically significantly different between treadmill and bicycle tests (45.8 ml/kg.min versus 37.3 ml/kg.min). Also age, waist circumference and the mean maximum heart rate percentage were statistically significantly different between treadmill and bicycle tests. Fire fighters who underwent bicycle testing had a lower $VO_{2\ max}$, but they were also

Table 1
Mean $VO_{2\ max}$ according to age, BMI, waist circumference, type of exercise test and maximum heart rate attained or not attained according to age.

	n	Percent	Mean $VO_{2\ max}$ (ml/kg.min) (SD)	p[1]
Age (years)				<0.001
<25	41	6.8	45.1 (9.4)	
25–34	194	32.2	48.2 (9.1)	
35–44	121	20.1	44.4 (10.5)	
45–54	156	25.9	40.0 (7.9)	
>=55	92	15.1	36.6 (7.6)	
Total	603	100.0		
BMI (kg/m^2)				<0.001
<25	199	41.2	47.8 (9.4)	
25–29.99	231	47.8	41.8 (8.7)	
>=30	53	11.0	33.5 (7.3)	
Total	483	100.0		
Waist circumference (cm)				<0.001
<94	281	58.4	49.2 (8.2)	
>=94	200	41.6	38.0 (7.5)	
Total	481	100.0		
Type of test				<0.001
Treadmill	430	71.3	45.8 (9.3)	
Bicycle	173	28.7	37.3 (8.4)	
Total	603	100.0		
Maximum heart rate according to age				0.002
Attained	317	53.2	44.5 (9.3)	
Not attained	279	46.8	42.0 (10.3)	
Total	596	100.0		

p[1] p value of ANOVA.
SD: standard deviation.

younger and more overweight and they reached lower maximum heart rates. In total 53.2% ($n = 596$) of tested persons reached the maximum heart rate for age. Of those who performed a treadmill test 64.4% reached the maximum heart rate according to age, comparing to 25.0% of those who performed a bicycle test. This difference is statistically significant (chi square, $p < 0.001$).

Maximal oxygen uptake was related to the type of test performed and the centre where the test had been performed. In Table 3, the mean $VO_{2\ max}$ of the 6 centres that delivered a minimum of 10 tests is compared. A statistically significant difference in mean VO_{2max} between centres was found even if treadmill and bicycle tests were compared separately. For the two centres that offered both types of test, VO_{2max} was significantly higher if performed on a treadmill than on a bicycle.

The results of a univariate general linear model analysis to detect the determinants and their interactions that best predict maximal oxygen uptake are shown in Table 4. Waist circumference was chosen as a measure of overweight over BMI because the relation between waist circumference and $VO_{2\ max}$ was stronger in a univariate regression model than the relationship between BMI and $VO_{2\ max}$. Determinants listed in Table 4 explained together 62% of the variation of $VO_{2\ max}$. As expected waist circumference was a statistically significant determinant of VO_{2max}. There was a significant interaction between age and the type of test indicating that the effect of age on the maximal oxygen uptake was dependent of the type of test. Other significant determinants were the performance of the test as expressed by the maximum heart rate percentage and the centre where the test had been performed.

Table 3
Mean $VO_{2\ max}$ according to centre for treadmill and bicycle tests separately ($n = 564$).

Centre	Treadmill tests		Bicycle tests		p[3]
	n	Mean VO_{2max} (SD)	n	Mean VO_{2max} (SD)	
Centre 1	354	45.1 (9.2)	11	33.0 (8.0)	<0.001
Centre 2	74	48.9 (9.2)	4	35.8 (5.6)	0.006
Centre 3			71	41.0 (7.5)	
Centre 4			28	32.9 (9.0)	
Centre 5			11	35.2 (8.6)	
Centre 6			11	36.8 (5.0)	
	p[1]	0.001	p[2]	<0.001	

p[1] p value of ANOVA comparing mean $VO_{2\ max}$ obtained by treadmill test between centres.
p[2] p value of ANOVA comparing mean $VO_{2\ max}$ obtained by bicycle test between centres.
p[3] p value of ANOVA comparing mean $VO_{2\ max}$ between different types of test per centre.
SD: standard deviation.

4. Discussion and conclusion

The aim of this study was to evaluate the current daily practice of aerobic capacity testing in Belgian fire fighters. The hypothesis that persons who performed a treadmill test reached a higher VO_{2max} than those who performed a bicycle test and that the maximal oxygen uptake varied significantly among test centres, was confirmed. The relationships between these not person related determinants and VO_{2max} remained significant even after correction for age and waist circumference, two important determinants of aerobic capacity.

Bicycle tests aren't commonly used in scientific investigations concerning aerobic capacity testing of fire fighters, in fact all investigations concerning this subject in recent literature used tread mill, step or stair mill tests, because these exercises, in contrast to cycling, resemble more the activities fire fighters do in emergency situations (Ben-Ezra and Verstraete, 1988; Bilzon et al., 2001; Bruce-low et al., 2007; Dreger et al., 2006; International Association of Fire Fighters, 2008; Kiss et al., 2010; Peate et al., 2002; Selkirk and Mc Lellan, 2004). In this study the data gathered during daily aerobic capacity testing in a sample of Belgian fire fighters were analysed in order to evaluate current practice in Belgium. In this sample 28.6% of aerobic capacity testing was performed on a bicycle ergometer.

Using data of current practice made it possible to gather VO_{2max} results from a large population of fire fighters, much larger

Table 2
Mean age, BMI, waist circumference, $VO_{2\ max}$ and maximum heart rate percentage for treadmill and bicycle tests.

	Total		Treadmill tests		Bicycle tests		p[1]
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	
$VO_{2\ max}$ (ml/kg.min)	605	43.3 (9.8)	430	45.8 (9.3)	173	37.3 (8.4)	<0.001
Age (year)	603	40.4 (11.5)	429	42.4 (11.4)	172	35.7 (10.3)	<0.001
BMI (kg/m^2)	482	25.9 (3.4)	315	25.7 (3.1)	165	26.3 (3.9)	0.062
Waist circumference (cm)	481	92.3 (10.4)	423	91.8 (10.3)	56	96.2 (10.5)	0.003
Maximum heart rate percentage (%)	596	99.7 (7.6)	427	101.4 (5.8)	168	95.5 (9.6)	<0.001

$p1$ p value of ANOVA comparing means between treadmill tests and bicycle tests.
SD: standard deviation.

Table 4
Determinants of maximal oxygen uptake. Univariate general linear model. ($n = 464$).

Dependent variable: $VO_{2\ max}$	
p	
Corrected model	<0.001
Intercept	<0.001
Waist circumference	<0.001
Age	0.001
Type of test	<0.001
Centre	0.004
Maximum heart rate percentage	0.012
Type of test*Age	<0.001

R Squared = 0.620.

than has been described until now (Barr et al., 2010; Kiss et al., 2010). This is a major strength of this study. However the multiplicity of centres where tests were performed, implicated that it was not possible to gather information on the testing protocols used. Analysing existing data also holds the limitation that social factor like motivation could differ and influence the results. This might be another weakness of this study. However we are confident that the fire fighters who underwent aerobic capacity testing in this study were motivated to deliver a maximum effort as the decision to be declared fit for their job depended on an adequate VO_{2max} result.

The mean $VO_{2\ max}$ (45.8 ml/kg.min) of fire fighters performing treadmill tests in our study was in close agreement with the values for fire fighters tested on treadmills in other studies (Barr et al., 2010; Ben-Ezra and Verstraete, 1988; Elsner and Kolkhorst, 2008; Kiss et al., 2010).

Waist circumference and age were significant predictors of maximal oxygen uptake. This relationship between parameters of obesity and age and maximal oxygen uptake have been demonstrated in several investigations (Fleg et al., 2005; Hawkins and Wiswell, 2003; Kiss et al., 2010; Laukkanen et al., 2009).

Maximum heart rate for age was more often reached in tread mill than in bicycle tests, suggesting workload was increased to a higher level in tread mill tests. Ben-Ezra and Verstraete (1988) found a significant difference in VO_{2max} between tread mill and stair climbing exercise. They suggest that the type of exercise test (and training) should be task-specific and that a stair mill test is preferable to a treadmill test. A bicycle test differs considerably from the physiological requirements of fire fighting and is therefore probably inferior to the cardio respiratory evaluation of fire fighters. Likewise, sport-specific tests are important in sports medicine (Wisløff and Helgerud, 1998).

On the other hand cardiologists often prefer to do a bicycle test because the ECG during a bicycle exercise test is of better quality and ischemic changes can be detected more adequately. Therefore it should be preferable to disconnect the cardiologic evaluation with exercise testing to detect ischemic changes on ECG from the aerobic capacity testing that should be task-specific. Fire fighters with cardiovascular risk factors should have a cardiologic check-up prior to the aerobic capacity testing.

This study also confirms that the mean VO_{2max} is higher in some centres independently of the type of test. This might be due to the use of different testing protocols. Some centres probably insist more to proceed to maximal exhaustion than others. This finding underlines the need for a stringent testing protocol. The International Association of Fire Fighters (IAFF) (2008) has formulated a protocol that could be an example for institutions and agencies that elaborate ability tests and criteria for fire fighters.

The decision to declare a fire fighter able to perform fire fighting tasks depends among other variables on his aerobic capacity. We therefore recommend that the exercise test should be specified and task-specific. A stringent testing protocol should be developed in order to gather results that are interpretable, comparable and useful for further investigations.

Conflict of interest

The authors declare no conflict of interest.

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Work demands during firefighting training: does age matter?[†]

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Work demands during firefighting training: does age matter?[†]

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Firefighting is known to be demanding, but low retirement age in this field means the capacity of the older worker to fight fires is less understood. In the Royal Fleet Auxiliary (RFA), firefighting is a critical secondary task that all personnel must be capable of. Heart rate (HR), work ability index and subjective work demand were obtained from 48 RFA personnel (18–58 years) during compulsory training. Measures of stature, mass, waist circumference (WC) and self-reported regular physical exercise were taken. The aim was to determine if cardiovascular responses were affected by age. Both cardiovascular and self-reported work demand scores were high but there was no evidence of any age-related increase in cardiovascular responses. Participation in extra-mural exercise and WC accounted for significant variance in both age-corrected HR and HR recovery. Results suggest that, in this sample, self-reported exercise and WC are more important determinants of HR response to fighting fires than age. Some limitations of the study are briefly discussed.

Statement of Relevance: There is renewed interest in the work capacity of older people, particularly in demanding tasks such as firefighting. The findings suggest that factors such as self-reported regular exercise and measures of overweight/obesity are more important determinants of cardiovascular responses to high physical demands than age in firefighters up to the age of 58 years.

Keywords: ageing workforce; firefighting; heart rate; physical demands

1. Introduction

1.1. The ageing workforce and task demands

Ergonomics is concerned with worker–task fit to ensure safe and efficient work practices. Of growing importance to this relationship is the increase in age profile of the workforce in many sectors of the economy (Kowalski-Trakofler *et al*. 2005). If the increased longevity of the workforce is not matched by maintenance in work capacity, then tasks must be adapted to account for changes in worker capability (Simonsen 1947). Thus, it becomes important for organisations to regularly reassess the implications of these changes to the existing task and work organisation.

Although employability, in terms of experience and expertise, may be higher in older workers the possibility of declining health status and physical capacity has been raised as a concern in ageing workforces. Despite research spanning over 60 years (Simonsen 1947, Welford 1958, Ross 2010), ageing is relatively poorly understood. Decrements in physical abilities include (but are not limited to) aerobic capacity, muscular strength, joint mobility and flexibility, reaction and movement time and balance (Welford 1958, Astrand *et al*. 2003, Benjamin and Wilson 2005). However, the nature of these decrements and ages at which the decline becomes critical to the task being performed is undefined. Indeed, Welford (1958) concluded that the same processes or abilities age at different rates in groups of people and also that different processes age at different rates in individuals. The result is that older workers tend to be a more heterogeneous group than younger workers. Sluiter and Frings-Dresen (2005) suggest that for most jobs age will not likely be a constraint to performance; however, for high-risk jobs, where the work demands may exceed safe or average human capacity, specific attention must be paid. There are few cases of jobs in which there are primary and secondary roles, one of which may be considerably more demanding than the other. Occupations such as police officers, ambulance workers and firefighters have been paid particular attention due to the public health issues surrounding these occupations (Sluiter and Frings-Dresen 2005). Firefighting leads to high heart rates (HRs) being maintained over long periods of time, which can stress a weakened cardiovascular system; data have shown

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that a firefighter's fitness is essential to the effective performance of the job (Elsner and Kolkhorst 2008).

Working at sea is a hazardous occupation and a high standard of fitness and health is integral for those working in the industry so that they are able to carry out their duties (Maritime and Coastguard Agency 2010). Although duties on board ships vary considerably within the Royal Fleet Auxiliary (RFA), firefighting is a critical shipboard task in which all personnel are required to be capable. While traditional, shore-based firefighters have the primary task of saving lives (von Heimburg *et al.* 2006), those at sea have the additional requirement of saving equipment and ensuring the functioning of the ship, particularly in operational war zones.

Regular physical exercise can be used as a means of promoting health benefits (Blair *et al.* 2001). Regular aerobic exercise attenuates age-related changes such as arterial compliance (Tanaka *et al.* 2000) and maximal oxygen consumption (Hawkins and Wiswell 2003) as well as changes in body, bone and blood composition (Bean *et al.* 2004) and muscular function (Myres 2003). The concept that the interaction of frequency, intensity and duration of exercise is more central than any in isolation is important when considering physical training components (Pollock *et al.* 1998); however, controversy remains regarding the 'optimal' balance between these (Helgerud *et al.* 2007).

Firefighting is known to be physically demanding, exacerbated by extreme external physical conditions, and thus requires a high degree of contribution from both the aerobic and anaerobic energy systems (Holmer and Gavhed 2007, Barr *et al.* 2010). Individuals climb ladders and stairs while using charged hoses and wearing extensive personal protective equipment (PPE) and self-contained breathing apparatus (SCBA). This combination of PPE and SCBA has been shown to negatively affect physical performance (Louhevaara *et al.* 1985). Owing to the nature of the work and the constraints of the PPE, complex physiological measurements in this field are difficult to undertake, even in experimental simulations (Holmér and Gavhed 2007). In simulation units or real fires, studies have monitored HR (Louhevaara *et al.* 1995, Smith *et al.* 2001) as an indirect indication of energy expenditure and cardiac strain.

Studies on firefighters have shown a decrease in aerobic capacity of ageing workers, when compared with a minimum required value (Saupe *et al.* 1991) and lowered work ability, particularly in those over 50 years (Kiss *et al.* 1994). Horowitz and Montgomery (1993) report decrements of 10 ml/kg per min between cohorts of firefighters aged 19–29 years and 50–59 years. However, these tasks tend to be forced-pace and even between studies there is disagreement as to magnitude of decrease. Furthermore, of the existing research on firefighting, Sluiter (2006) points out that less than 10% of studies report on issues relative to ageing. One must also consider whether these changes are practically important; do the declines occur to such a degree as to impair the task that is being performed, or can older workers compensate by applying their resources in a more economical way, as suggested by Salthouse (1991)? Sluiter (2006) reiterated that the work ability of individuals must be considered in relation to the specific job demands – those that may exceed average human capacity – as these are those most likely to lead to risk of work-related problems.

The present paper reports an investigation of work demands in firefighting training, which was carried out on a group of merchant seafarers who were required to be able to fight fires at sea in emergencies. The study was motivated by two concerns. First, that firefighting was not the trainees' main occupation; however, it was a critical task and thought to be more arduous than those performed during primary duties. Second, unlike professional firefighters, the organisation had no fitness or selection tests and the age of the workforce was known to be increasing. Thus, although the demands of firefighting have been widely investigated, this population is unlike those considered in the wider literature. While it is known that older individuals experience greater cardiovascular demands with age, the interaction of these with lifestyle factors such as exercise and weight management are less well understood. Given the nature of the work that the RFA does, it is important to consider the impact that secular changes may have on the capacity of the workforce to guide organisational health and well-being policy making.

1.2. Aims

The study had three aims. First, to quantify the physiological responses of seafarers during fire training in a simulator, using HR intensity as a measure of cardiovascular strain. Second, to determine whether older individuals experienced greater cardiovascular demands due to their age, as it is questionable as to whether findings of previous research on professional firefighters can be generalised to a population of ageing seafarers. The management of the organisation is required to continually assess the risk associated with tasks such as these as part of their 'duty of care' to their employees. Third, to identify whether factors such as exercise participation, BMI or waist circumference (WC) determined cardiovascular responses to the training. Furthermore, it is unknown whether or not the extent to which age or lifestyle-related declines in fitness affecting these responses were actually operational implications.

2. Method

2.1. Physical measures

Individual stature, mass and WC measures were taken according to guidelines set by the International Society for the Advancement of Kinanthropometry (Marfell-Jones *et al.* 2006). HR measures were taken using Polar^{TM} RS400 (Polar Electro, Kempele, Finland) conductive chest straps and wrist watches. HR was recorded every 5 s throughout the period of investigation and data were stored on the watch to avoid interference with the fire training procedures. Data were subsequently downloaded post training. The chest strap was worn under the standard firefighter protective ensemble of boiler suit, fire-retardant 'fearnought' suit, socks, Wellington boots, gloves, SCBA, face mask, hood and helmet. Age predicted maximal HR (APHRmax) was predicted using the method of *APHRmax = 220 (beats per min (bpm)) – age (years)*; each individual's mean working HR was then compared with their individual APHRmax (%APHRmax). This was used to estimate work intensity relative to maximum predicted HR.

2.2. Self-report measures

The Work Ability Index (WAI) is a self-report tool widely used in research on the ageing workforce (Tuomi *et al.* 1997, van den Berg *et al.* 2008). It provides a global measure of employee perceptions of their work capacity in relation to their lifetime best and is known to be a valid and reliable (de Zwart *et al.* 2002) tool that predicts occupational disability (Seitsamo and Ilmarinen 1997, Tuomi *et al.* 1998, Karpansalo *et al.* 2004) and early retirement (Costa and Sartori 2007). The WAI regards work ability as a positive resource of health and relates this to work task demands and also includes the effects of diseases on perception of health and lifestyle factors. Several self-report measures are available to evaluate task demands. The NASA task load index (TLX) is widely used and gives an indication of perceived work demands in the sub-categories of physical, mental and temporal demands, frustration, performance and effort measures. The TLX is often used for the evaluation of employees' immediate perceptions of workload, either in real systems or in simulators (Hart and Staveland 1988) and is well used in human performance studies. Its multidimensionality makes it a useful tool that is easily administered (Young and Stanton 2005).

Within the structure of the WAI, several demographic questions not applicable to the study were removed and replaced with measures of self-reported activity data based on questions from the Baecke questionnaire (Baecke *et al.* 1982). These included the number of hours of exercise per week (rating scores in parentheses): never (1); <1 h (2); 1–2 h (3); 2–3 h (4); >3 h (5). Also rated was the intensity of exercise: low (1); moderate (3); high (5). A subset of this questionnaire was used due to time demands during the fire training. Parahoo (1997) maintains that additional information regarding exercise is useful for constructing profiles and exploring correlations with other attributes. There is also some evidence that even simple questions regarding duration and intensity of exercise are valid and reliable (Davis *et al.* 2001). Additional data such as smoking habits were collected in the same questionnaire.

2.3. Procedure

All participants were attending a compulsory basic sea survival course at a dedicated facility, where firefighting training units (FFTUs) simulate galley and engine room fires within a multilevel compartment. This is a high-fidelity simulator and was a pragmatic way of gaining access to participants, so that the demands of fighting a real fire could be estimated. This training facility was accepted as a reasonable simulation of firefighting on board, as collecting data either during a real emergency or during on-board training is impractical due to interference with operational activities. On reporting to the training facility, personnel were invited to participate in the trial. Once informed consent was obtained, anthropometric measures were taken and the WAI completed. The researchers returned on the final fire training afternoon to administer the main trial. Each participant was fitted with a Polar^{TM} RS400 HR monitor before proceeding to the FFTU, where the correct PPE was donned. As testing was performed during actual training, the exact manoeuvres within the FFTU were not within the control of the researchers. Royal Navy (RN) fire instructors managed the fire training session, but had been briefed as to the requirements of the study.

The same routine was followed each time. Participants would do a 'mock' walk-through with the instructor, after which they were randomly allocated to one of two groups with approximately five to six team members. The first group went 'on air' (fitted face masks and activated breathing apparatus sets) and entered the FFTU while the second group waited outside. With the fire successfully 'extinguished', the first group returned to the muster area, at which point the second group went 'on air' and entered the FFTU.

The first group changed their used SCBA sets in readiness for the second rotation. Once the second group returned, the first entered the FFTU for the second exercise. The second group followed the same procedure so that each person had two rotations into the FFTU to 'fight' the fire. This is common practice within fire teams, where one group relieves another to allow recovery and replenishment of the SCBA. These respective work periods were categorised as 'run 1' and 'run 2' and are referred to in this manner hereafter. Each run took an average time of 11 ($\pm$3) min. At the completion of the two runs, as soon as safely possible, participants were required to sit quietly for 5 min to obtain recovery HR measures, as described by Brouha (1967) at 0.5–1.0 min (recovery 1) and 2.5–3.0 min (recovery 2). During this time, the participants rated task difficulty of the fire training on the NASA TLX questionnaire.

2.4. Data analysis

Data analyses were performed using SPSS ver. 16 (SPSS Inc., Chicago, IL, USA). The data were checked for normality of responses using Shapiro-Wilk and all were found to be normally distributed, except for WAI scores, which were positively skewed. Pearson's product moment correlation coefficients were calculated to determine relationships between variables. The main and interaction effects of individual and lifestyle variables with work and recovery measures of HR were examined by multiple linear regression (MLR) analyses. Due to the small sample size, a pragmatic approach was utilised, which used the Pearson's correlation as a guide. In this way, a maximum of four variables were considered as potential predictors. The high number of correlations between age and several other predictor variables led to a two-stage approach to the MLR analysis, both enter and stepwise methods (with age forced in first as a control variable). The results from these were further verified in a second analysis using the stepwise method to assess the relative strength of each predictor's contribution. Probability values of $p < 0.05$ were accepted as statistically significant.

Initial investigation of the data showed a positive relationship ($R^2 = 0.33$) between number of hours and intensity of exercise; thus, those reporting more frequent habitual exercise rated these as being of a higher intensity than that reported by less active participants. Because both duration and intensity of exercise are important determinants of physiological benefits (Astrand *et al.* 2003, Pollock *et al.* 1998) an interaction variable was created by multiplying duration and intensity to create a habitual exercise load (duration $\times$ intensity; DxI).

2.5. Participants

The participants in the study were merchant seamen serving in the RFA, a Ministry of Defence-owned fleet. The RFA plays a support role to the RN with a range of operational capabilities and can be required to enter war zones. RFA personnel are thus required to be able to perform firefighting and flood and damage control as secondary activities to their primary role (which are regular sea-going trades such as engineers, stewards, deck hands and cooks). The RFA has no retirement age and the average age of personnel is 42 years (Bridger *et al.* 2010), with an increasing number of the workforce remaining into their later years. Fitness standards are not applied to this population, unlike in similar professions where high physical workloads are common, such as the RN (Royal Navy Fitness Test) and the UK fire service (National Firefighter Selection Tests). A combination of organisational factors mean that many RFA personnel are required to perform similar, often physically demanding duties at the age of 45 years as they undertook at 18 years (Leonard 2003). All participants were in possession of a current ENG 1 (Seafarers medical examination), as required by Maritime and Coastguard Agency standards and thus deemed fit for work at sea by a registered medical doctor. This ENG 1 is the mandated measure of 'fitness for duty' for all merchant mariners.

Altogether, 48 male, non-smoking RFA personnel volunteered for the trial and gave written, informed consent to take part in a Ministry of Defence Research Ethics Committee-approved protocol during March–June 2010. The mean ($\pm$SD) demographic and anthropometric characteristics of the sample are reported in Table 1. In this sample of RFA personnel, 6% reported taking no exercise at all, 23% did 1 h per week or less, 35% between 1 and 3 h per week and 36% reported exercising more than 3 h per week. Based on measures of BMI (World Health Organisation 2010), 28% of the sample was classified as normal weight, 48% as overweight and 24% as obese.

Table 1. Mean ($\pm$SD) of anthropometric and demographic characteristics for the present sample (n = 48).

Age (years)	36 ($\pm$11.6)
Stature (cm)	178 ($\pm$5.8)
Mass (kg)	87.7 ($\pm$13.3)
BMI (kg/m^2)	27.8 ($\pm$3.9)
Waist circumference (cm)	99.3 ($\pm$11.6)
Time in service in RFA (years)	5.6 ($\pm$8.8)

RFA = Royal Fleet Auxiliary.

3. Results

3.1. Cardiovascular responses

Table 2 illustrates the average HR responses to both the fire training and recovery periods. Age-corrected values (%APHRmax) for the work periods are also shown as these take the decline of aerobic capacity due to age into consideration. HR for both runs 1 and 2 averaged at 136 bpm, with standard deviations of between 19 and 22 bpm; coefficients of variation for these data are between 14% and 16%. There were no significant differences between mean HR responses for runs 1 and 2 ($p = 0.52$, $t = 0.65$, degrees of freedom (df) = 43). Mean HR for the entire training session (encompassing both training periods and the short break in between) was 132 (±18) bpm. On average, personnel were working at 74–75% of their APHRmax (±11–13%). Average recovery HR over the period 0.5–1.0 min post exercise (recovery 1) was 131 (±23) bpm and between 2.5–3.0 min (recovery 2) it was 126 (±23) bpm. The average reduction between these two recovery HRs was only 5 bpm.

3.2. Subjective work ability and task demands

Mean score on the WAI was 44 (±4), classified as 'excellent' work ability. Scores ranged from 35 to 49 (good–excellent work ability), Shapiro-Wilk analysis showed a significant positive skew to the data. The NASA-TLX scores 0–20 on six component scales with higher scores indicating higher demands. Mean summed NASA-TLX score for the sample was 75 (±12.6), 63% of the maximum 120 point summated score. Component scales reflected similar results to those reported before in a similar population group (Bridger *et al.* 2010), where results were clustered around the midpoint. The scales can be used as either a summed total score or as unweighted single subscale items (Hart 2006). The second approach was used in this study in order to determine the relative subjective composition of the firefighting task. Physical demands (15 ± 4), effort (16 ± 3), performance (15 ± 3) and mental demands (14 ± 4) were the highest rated, while temporal (11 ± 5) and frustration (7 ± 5) scores were close to or below the midpoint of subjective demands.

Table 2. Mean (±SD) heart rate (HR) responses to fire training (n = 48), both absolute and as a percentage of age-predicted maximal HR (%APHRmax).

	Mean (SD) bpm	%APHRmax (SD) (%)
Run 1	136 (19)	75 (11)
Run 2	136 (22)	74 (13)
Recovery 1 (0.5–1.0 min post exercise)	131 (23)	
Recovery 2 (2.5–3.0 min post exercise)	126 (23)	

bpm = beats per min.

3.3. Correlation matrix

Table 3 presents the results of Pearson's correlation analysis; all of the variables in the study were examined within the analysis, but only statistically significant coefficients are presented. Cohen (1988) reports that coefficients of 0.3–0.5 are considered 'moderately strong' and those above 0.5 'strong'. Correlations between age and a number of demographic and anthropometric factors were moderate; however, no significant relationship between age and cardiovascular responses was seen. Although exercise intensity, and to a lesser extent duration, both correlated with cardiovascular responses, the composite interaction of these correlated more strongly than each in isolation (Table 3).

Positive correlations of age with BMI (r = 0 .31, df = 47, $p \leq 0.05$) and with WC (r = 0.34, df = 47, $p \leq 0.05$) and a negative relationship between age and DxI ($r = -0.30$, df = 47, $p \leq 0.05$) were observed, both 'moderately strong'. Older personnel were more likely to have higher BMI and WC and participate in fewer hours of exercise than their younger counterparts. The relationship between exercise and obesity markers has been noted previously (Aadahl *et al.* 2007) when considering cardiovascular disease risk factors. The strongest correlation was that between WC and age ($r = 0.34$, $p \leq 0.05$, df = 47).

BMI ($r = 0.32$, $p \leq 0.05$, df = 47) and WC ($r = 0.49$, df = 47, $p \leq 0.01$) both correlated positively with recovery HR while WC correlated to a weaker extent with mean HR ($r = 0.33$, df = 47, $p \leq 0.01$) in the expected direction (i.e. greater BMI and WC were associated with higher HR). WAI was negatively correlated with age ($r = 0.30$, df = 47, $p \leq 0.05$), strongly with both BMI ($r = -0.53$, df = 47, $p \leq 0.01$) and WC ($r = -0.55$, df = 47, $p \leq 0.01$); results indicated lower reported work ability in older individuals and those with high BMI and WC measures. BMI and WC correlated more strongly with work ability than did age. WC correlated more strongly with the HR measures than did either BMI or age. Task demands as reported on the NASA TLX showed no relation with physiologically determined task demands or with any demographic or subjectively reported variable.

Both absolute and age corrected HR, being the dependent variables, correlated negatively with DxI (r between -0.31 and -0.51, df = 47, $p \leq 0.01$ and $p \leq 0.05$). This indicates that HR responses were

Table 3. Inter-correlations of all study variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Age	–														
2. BMI	0.31*	–													
3. WC	0.34*	0.90**	–												
4. Duration of sport (code)			−0.288**	–											
5. Intensity of sport (code)	−0.425**		−0.338*	0.578**	–										
6. Exercise (DxI)	−0.30*		−0.31*	0.816**	0.888**	–									
7. WAI score	−0.30*	−0.53**	−0.55**	0.294*			–								
8. NASA TLX total								–							
9. Mean HR (run 1)									–						
10. %APHRmax (run 1)	0.35*		0.36*	−0.287*		−0.31*			0.89**	–					
11. Mean HR (run 2)			0.33*	−0.329*		−0.34*			0.64**	0.60**	–				
12. %APHRmax (run 2)	0.34*		0.39**	−0.404*	−0.396*	−0.43**			0.55**	0.68**	0.93**	–			
13. Recovery 1		0.32*	0.49**	−0.351*	−0.422**	−0.47**	−0.42**		0.51**	0.55**	0.69**	0.71**	–		
14. Recovery 2			0.42**	−0.373*	−0.373*	−0.51**	−0.36**		0.83**	0.48**	0.63**	0.64**	0.69**	–	
15. Mean HR (run 1, rest, run 2)			0.32**			−0.35*			0.83**	0.78**	0.83**	0.74**	0.68**	0.69**	–
Mean	37.0	27.8	99.3	4.0	2.0	7.4	44.4	76.0	136.0	74.0	136.0	89.0	130.0	124.0	132.0
SD	11.8	3.9	11.6	1.0	1.0	5.1	4.2	13.0	19.0	11.2	22.0	12.3	23.0	22.0	18.0

WC = waist circumference; DxI = duration × intensity; WAI = Work Ability Index; TLX = task load index; HR = heart rate; APHRmax = age-predicted maximal HR.
n = 48; $*p \leq 0.05$; $**p \leq 0.01$.
Note: Non-significant results have been omitted.

significantly lower in personnel who reported participating in longer periods of intense exercise.

3.4. Model generation

Working HR, %APHRmax and recovery HR were used as outcome measures in the MLR and a maximum of four predictor variables were used: age; DxI; WC; WAI. The use of single terms in the MLR model depends on the assumption of 'additivity', which, according to Aiken *et al.* (1991), should always be tested. Accordingly, an interaction term was developed as the product of the two main effect terms and therefore it was DxI used in the MLR as opposed to either in isolation.

Relative to the aims of the study and due to the high co-linearity between age, WC, DxI and BMI, initial MLRs forced age into the model and then offered the remaining independent variables up to the model stepwise. However, age was not returned as a significant contributor to the model. The models were then re-run using the stepwise method with the four independent variables. The results from these MLRs are shown in Table 4.

No significant models emerged with regard to absolute working HR responses (runs 1 and 2). WC predicted 13% of the variance in mean %APHRmax (run 1) and DxI predicted 17% of the variance in mean %APHRmax (run 2). DxI and WC together accounted for 29% of the variance in the first period of recovery and, in the second, 24% of the variance was accounted for by DxI. This model generation indicates that, for many of the HR responses measured in the current study, the main predictive variables are self-reported participation in exercise and WC. Even when age was forced in initially, it did not explain a significant amount of variance within the models.

4. Discussion

This study aimed to investigate work demands on a population of ageing seafarers performing fire training in a shore-based simulator. This is a civilian population performing tasks akin to those of the RN and neither the work demands nor responses to this have been investigated within this organisation. Much of the research in this area has been on professional firefighters, who have both a minimum fitness standard and a retirement age; thus, findings based on this research may not be generalised to that investigated within this study where neither of these apply. The relationship between ageing and factors such as health and lifestyle are not well understood and the current study aimed at elucidating these relationships in this population.

Table 4. Results from stepwise multiple linear regression analysis.

	Mean %APHR-max (run 1)		Mean %APHR-max (run 2)		Recovery HR 1 (0.5–1.0 min)		Recovery HR 2 (2.5–3.0 min)	
	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2
Regression steps and effect tested								
1. Exercise (DxI)			−0.412	0.169*	−0.360	0.206*	−0.493	0.243*
2. Waist circumference	0.364	0.133*			0.303	0.083*		

APHRmax = age-predicted maximal heart rate; HR = heart rate; DxI = duration × intensity.
n = 48; $^*p \leq 0.05$.

The HR responses recorded during the fire training in this study are indicative of 'very heavy work' (Astrand *et al.* 2003), in agreement with the literature, where HR responses are often close to, or exceed, maximal values (Bilzon *et al.* 2001, Holmer and Gavhed 2007, Barr *et al.* 2010). Participants worked at, on average, 75% (±12%) of APHRmax; this corresponds to the mean subjective NASA TLX physical demands score of 15/20 (75%). The low subjective temporal demands scores (55% ± 25%) reported here suggest that the work is largely self-paced, possibly as a result of the structure and teaching element of the course. However, in a real fire, time pressure is likely to be much higher due to the urgency of the task and the physiological costs much greater. Thus, despite the high fidelity of the simulator, the present data may underestimate the demands of real firefighting. It appears that, in this situation, self-pacing may account for the lack of correlation between age and higher cardiovascular demands during fire training. Elsner and Kolkhorst (2008) suggest that firefighters work at a self-selected pace, depending on the urgency of the situation, fitness and fatigue levels and the pace of the least able firefighter in the group.

When considering the intercorrelations of the variables, relationships between age and absolute working and recovery HR data were not statistically significant, in this potentially self-paced task. Positive correlations between age and %APHRmax are not discussed as this is likely to be an artefact of shared variance (i.e. age did not correlate with absolute HR responses but did correlate with age-corrected HR (normalised as %APHRmax) because the practice of normalising participants' HRs by age meant that the independent variable, age, and the dependent variable, age corrected HR, automatically co-vary).

Older personnel were significantly less likely to participate in intense exercise and had higher BMI and WC measures and lower subjective WAI. However, the correlations with WAI and the HR measures were stronger for BMI and WC than for age. So, although older participants tended to be heavier, BMI and WC play the most important role. Although the WAI data were skewed with limited range (few personnel reporting anything other than good or excellent work ability) the correlations with age, BMI, WC and exercise participation were in the expected direction. Significantly lower WAI scores were reported by older individuals with higher BMI and WC measures; thus, perceived work ability in older adults is exacerbated by indicators of overweight. Individuals with lower WAI scores had significantly higher recovery HRs at both recovery 1 and recovery 2, potentially indicating more difficulty in coping with demands of the training.

The detrimental effect of excess adiposity on perceived work ability is interesting, despite the fact that all individuals rated work ability above 'good'. The skew to the WAI data is likely due to the survivor effect, where stoic individuals remain in the organisation while those who feel they cannot cope self-select themselves out. Leonard (2003) suggests that the higher potential hazards of working at sea and the extended periods of absence from family and home are likely to lead to significant self-selection. Recent data show that the most common causes for medical retirement in the RFA are musculoskeletal disorders, cardiovascular disorders and mental disorders; the highest risk of retirement (per man year) is in 40–49 year olds, with the highest absolute medical retirement rate in those over 50 years old. Despite the range limitation on the WAI scores, correlations with the recovery HR data constitute a criterion validation of the WAI.

Individual factors with the highest number of correlations with working and recovery HR were WC and DxI, where those with lower WC measures and higher reported participation in exercise responded to the fire training with significantly lower working and recovery HRs. The correlation matrix shows a degree of co-linearity between age, WC, BMI and DxI, it is difficult to separate out the effects of the different variables. However, as a means of separating effects of this co-linearity, use was made of MLR analysis.

Regression analysis showed that significant models predicting cardiovascular responses could be drawn from two main criterion variables, DxI and WC measures, either singularly or when combined. The explained variance in these models ranged from 13% to 28%. Two of the models have r-squared values of 0.24 and 0.29, equivalent to Pearson's *r* values of 0.49 and 0.54, which Cohen (1988) would refer to as moderate to strong magnitudes. Despite the small number of subjects, the regression analyses led to fairly consistent results in %APHRmax and recovery HR. Age did not account for any variance in HR responses, suggesting that, within this sample, not participating in exercise and having more abdominal fat are more important in predicting higher cardiovascular demands than is advancing age, despite the co-linearity. The strongest models are those for recovery HR, with DxI responsible for 24% of the variance 3 min post-exercise cessation and WC for 22% in recovery HR 1 min post exercise. Theoretically, this argument is strong, as higher cardiovascular fitness leads to lower recovery time (Astrand *et al*. 2003). Additionally, these findings are even more remarkable because the study was done *in situ* with a diverse sample. While the predictive power of the models is not strong, they give insight into this process; for management, the take-home message is that while research has shown decreased capacity with age, within this task and population, fitness and adiposity may be more operationally relevant. Exercise participation is an important factor in reducing cardiovascular demand in this population when performing demanding work, based on measures of self-reported exercise. This is particularly important for the organisation at hand where positive policies regarding health and fitness may play a role in mitigating the effects of ageing and ensuring a capable workforce for the future.

In the age range considered in this study (20–58 years) it appears that health and lifestyle factors override the effects of ageing. The present study demonstrates that these factors can moderate the effects of ageing on work capacity in firefighting. Within this organisation, policy options may limit use of a 'cut-off' age. Thus, the ageing demographic is likely to remain; however, other factors (such as exercise and weight management) may be modified to encourage a healthier workforce. It is important for the organisation to consider that, in order to mitigate the effects of the ageing workforce, strategies regarding encouragement of employee exercise participation and reduced levels of obesity are vitally important. Opinion regarding public health policy appears to be divided as to which of either physical activity or obesity should be the focus (Weiler *et al*. 2010).

A number of limitations existed within the study due to data being collected within an established training schedule. Time constraints did not allow for administration of a sub-maximal test to determine aerobic capacity and individual relationship with HR. Use of predictive equations (as seen in the APHRmax) is inherently inaccurate. However, it does allow for inter-individual comparisons and is widely used to reflect age-related decrements. There was a high degree of inter-individual variability in responses; unfortunately, due to the manner of the fire training simulation, the researchers had no control over the intensity of work and confounders of self-pacing and team dynamics are likely. Despite these limitations, the data and results from this study reflect a realistic view of the cardiovascular demands faced by personnel undergoing firefighting training from a sample of serving RFA personnel. Despite these limitations and the lack of experimental control, statically significant models were generated and these accounted for up to 29% of the variance in the cardiovascular response to training.

5. Conclusions

The study shows that firefighting training is an arduous task with high physical demands; cardiovascular responses averaged 136 bpm, although high individual variability was found. This HR equated to approximately 75% of APHRmax, during a self-paced task. Increasing age did not appear to be related to higher cardiovascular responses. In this sample, up to the age of 58 years, cardiovascular responses to physically demanding work depended more on self-reported exercise and WC measures than on age, although older individuals had lower exercise rates and higher WCs. The findings of the study are grounded in ongoing ageing research in generating informed and evidence-based policy options with regard to the ageing workforce. Age was only indirectly associated with HR and HR recovery. Older participants tended to have a higher BMI and WC than their younger counterparts and they exercised less. Controlling for BMI, WC and exercise participation, there was no direct effect of age within the range 20–58 years. These findings highlight the importance of maintaining a healthy weight and active lifestyle in ageing workers who may be required to perform arduous tasks in emergencies.

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Are job and personal resources associated with work ability 10 years later? The mediating role of work engagement

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Are job and personal resources associated with work ability 10 years later? The mediating role of work engagement

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Using a two-wave 10-year longitudinal design, this study examined the motivational process proposed by the Job Demands-Resources (JD-R) model. The aim was to examine whether work engagement acts as a mediator between job resources (i.e. supervisory relations, interpersonal relations and task resources) and personal resources (self-esteem) on the one hand and future work ability (i.e. a worker's functional ability to do their job) on the other. The second aim was to investigate the mediating role of engagement between past work ability and future work ability. Structural equation modelling was used to test the mediation hypotheses among Finnish firefighters (N = 403). As hypothesized, engagement at T2 fully mediated the impact of job and personal resources at T1 on work ability at T2. In addition, the effect of work ability at T1 on work ability at T2 was partially mediated by engagement at T2. These results indicate that job and personal resources may have long-term effects on engagement, and consequently on work ability, thus expanding on the propositions of the JD-R model. The results show a dual role of work ability, as a health-related resource that may foster engagement and an outcome driven by the motivational process proposed by the JD-R model.

Keywords: engagement; job resources; personal resources; self-esteem; work ability; firefighters; longitudinal

Introduction

The well-established Job Demands-Resources (JD-R) model (Demerouti, Bakker, Nachreiner, & Schaufeli, 2001) assumes that work characteristics, such as job demands and job resources, have either positive or negative effects on employee well-being. The basic assumption of the JD-R model is that two distinct psychological processes — the health-impairment process and the motivational process — are differently related to well-being. Firstly, the health-impairment process assumes that job demands lead to burnout, and consequently to ill-health. Secondly, the motivational process assumes

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that job resources lead to work engagement, which, in turn, has a positive effect on organizational outcomes. According to the later formulations of the JD-R model, personal resources, such as self-esteem, may have similar motivational potential to that of job resources (Xanthopoulou, Bakker, Demerouti, & Schaufeli, 2007). However, one limitation of the JD-R model has been its neglect to elucidate the relationship between job and personal resources and health-related outcomes. Nevertheless, the motivational process initiated by job and personal resources, through engagement, may also lead to positive health-related outcomes (e.g. Hakanen & Roodt, 2010), such as work ability.

Work ability refers to workers' ability to carry out their work, that is, having the occupational competence, the health required for the job and the occupational virtues that are required for managing the work tasks (Tengland, 2011). Thus, work ability refers to functional capacity to meet the requirements of the job. So far, work ability research has not studied the motivational aspects of human resources with the same intensity as it has biographical and life-style factors (e.g. age, alcohol consumption, physical exercise, BMI) and work-related factors (e.g. mental and physical work demands, management) (for a review, see Van den Berg, Elders, Zwart, & Burdorf, 2009), despite the fact that affective-motivational factors such as work engagement are considered essential factors related to work ability (e.g. Ilmarinen, 2009). To conclude, it is not yet clear what the relationships are between engagement and work ability, and between self-esteem and work ability; and the long-term impacts that both job and personal resources may have on work ability via engagement.

Therefore, in the present study, using the Conservation of Resources (COR) theory (Hobfoll, 1989), the Broaden-and-Build (BaB) theory (Fredrickson, 2001) and self-enhancement theory (Jones, 1973) as theoretical frameworks, we examined the motivational properties of job and personal resources in the JD-R model in a sample of Finnish firefighters. Based on those theories, we argue that both job and personal resources are significantly related to future work engagement, and consequently, to work ability. More specifically, we examined whether work engagement acts as a mediator between job resources and self-esteem (a personal resource) on the one hand, and work ability on the other. In addition, we examined whether work engagement mediates the effect of past work ability on future work ability. Thus, we investigated the dual role of work ability in the motivational process as proposed in the JD-R model. More particularly, we studied the role of work ability as a health-related outcome of the motivational process, and simultaneously its role as a health-related resource that may boost work engagement and consequently predict not only directly but also indirectly future work ability across a 10-year follow-up period.

Job resources and work engagement in the JD-R model

The basic assumption of the JD-R model is that job resources are positively related to work engagement, which, in turn, is related to positive outcomes, thus constituting a motivational process (Bakker & Demerouti, 2007). As such, job resources refer to those physical, psychological, social or organizational aspects of the job that may help to achieve work goals, reduce job demands and the related physiological and psychological costs, and stimulate personal growth and development (Demerouti et al., 2001). Additionally, work engagement refers to an affective-motivational state of work-related well-being that is characterized by vigour, dedication and absorption (Schaufeli, Salanova, González-Roma, & Bakker, 2002).

In the current study among firefighters, we included three job resources that prior studies have identified as important resources for this professional group: (1) *supervisory support* (e.g. Haslam & Mallon, 2003; Mitani, Fujita, Nakata, & Shirakawa, 2006); (2) *supportive interpersonal relations* (e.g. Saijo, Ueno, & Hashimoto, 2007); and (3) *task resources* (e.g. Lusa, Punakallio, Luukkonen, & Louhevaara, 2006). Self-Determination Theory (SDT; Deci & Ryan, 2000; Van den Broeck, Vansteenkiste, de Witte, & Lens, 2008) offers a plausible explanation for the choice of the three selected job resources. According to SDT, intrinsic motivation will flourish if three basic psychological needs — autonomy, competence and relatedness — are satisfied. For firefighters, autonomy may be related to their ability to make decisions concerning their work tasks (i.e. task resources); competence may be related to their opportunities to use their skills at work (i.e. task resources); and social support from colleagues and supervisors to the relatedness need of SDT (i.e. supervisory support and interpersonal relations), all of which are consistently shown to be related to work engagement (e.g. Hakanen & Roodt, 2010; Van den Broeck et al., 2008).

COR theory (Hobfoll, 1989) describes pathways from job resources to employee health. Firstly, the basic tenet of the resource-orientated COR theory is that people strive to retain, protect and build resources that they value. Moreover, these resources, such as conditions (i.e. job resources) or personal characteristics (i.e. self-esteem) are salient in gaining new resources and in enhancing health. More precisely, those with greater resources are less vulnerable to stress, and additionally they are more capable of future resource gain, and consequently will have better protection against ill-health. To summarize, the COR theory, alongside the JD-R model, assumes that high levels of resources can be beneficial for health (and work ability) in the long term.

Empirically, the motivational process of the JD-R model, leading from job resources through engagement to positive organizational outcomes, has been convincingly supported (for an overview, see Schaufeli & Taris, 2014). For example, organizational outcomes such as customer loyalty (Salanova, Agut, & Peiró, 2005), organizational commitment (Hakanen, Schaufeli, & Ahola, 2008) and innovativeness (Hakanen, Perhoniemi, & Toppinen-Tanner, 2008) have been examined. In contrast, the link between job resources via work engagement to *health-related* outcomes, such as work ability, has rarely been investigated. Nevertheless, based on the COR theory we assume that job resources may also be positively related to health-related outcomes via engagement. In fact, some evidence exists on the positive association between job resources and/or engagement and health-related outcomes (e.g. Hakanen & Schaufeli, 2012; Parzefall & Hakanen, 2010). Additional evidence corroborates the positive relations between work engagement and health (e.g. Langelaan, Bakker, Schaufeli, van Rhenen, & van Doornen, 2006; Seppälä et al., 2012) and between work engagement and work ability (e.g. Airila, Hakanen, Punakallio, Lusa, & Luukkonen, 2012; Hakanen, Bakker, & Schaufeli, 2006).

In addition, previous studies have shown a long-term impact of resources on well-being, thus supporting the assumption of COR theory of a slow accumulation process resulting in long-term resource gains. For example, a study among the Finnish working population (Hakanen, Bakker, & Jokisaari, 2011) showed that skill variety (a job resource) negatively predicted burnout 13 years later, even after controlling for the concurrent levels of skill variety. In addition, a study among Dutch employees showed that various job and personal resources were positively related to work engagement over a follow-up period of 18 months (Xanthopoulou, Bakker, Demerouti, & Schaufeli, 2009). Similarly, Hakanen, Peeters, and Perhoniemi (2011) found that various job resources predicted both work engagement and work-family enrichment over a three-year follow-up period, further supporting the notion of long-term resource gain processes. Taken together, these findings suggest that the motivational process proposed by the JD-R model may also lead to better health — although the primary health outcomes may often follow the health-impairment pathway. Therefore, based on theoretical reasoning as well as earlier empirical findings, we formulate the following hypothesis:

Hypothesis 1: Job resources at T1 will be positively related to work ability at T2 through work engagement at T2. In other words, work engagement will mediate the relationship between job resources and future work ability.

Personal resources in the JD-R model

A more recent formulation of the JD-R model proposes that personal resources may have similar motivational potential to that of job resources and may be positively related to work engagement, and consequently to positive work-related outcomes (Xanthopoulou et al., 2007). By definition, personal resources are positive self-evaluations that are linked to resilience, and refer to an individual's sense of ability to successfully control and impact on his or her environment (Hobfoll, Johnson, Ennis, & Jackson, 2003). In the current study, we included self-esteem as a typical personal resource that may be beneficial for achieving positive work-related outcomes (e.g. Hobfoll, 2001). Self-esteem refers to a positive evaluation of one's worth, significance and ability as a person (Janssen, Schaufeli, & Houkes, 1999; Rosenberg, 1965). According to Hobfoll (2001), self-esteem can be viewed as a personal characteristic that is valued in its own right. Indeed, self-esteem — as a personal resource — may play an important role in human functioning in two ways.

First, COR theory (Hobfoll, 1989) proposes that personal resources (e.g. self-esteem) tend to generate other resources, which, in their turn, may result in better well-being. More precisely, according to COR theory, the loss or gain of self-esteem results in stress or well-being, respectively. In a similar vein, Rosenberg, Schooler, Schoenbach, and Rosenberg (1995) have emphasized the value of global self-esteem as a predictor of (psychological) well-being. Secondly, self-enhancement theory (Jones, 1973; see also Rosenberg et al., 1995) provides a theoretical explanation for the underlying mechanism that links self-esteem to health-related outcomes. According to this theory, people strive to protect and enhance their feelings of self-worth (i.e. self-esteem). This maintenance of self-esteem leads to self-protective motives, and thus to the beneficial development of well-being. Therefore, based on these theories we assume that self-esteem — as a personal resource — is an antecedent of work engagement (i.e. work-related well-being), and consequently related to work ability.

Indeed, some evidence exists of the positive relationship between self-esteem and well-being (for a review, see Baumeister, Campbell, Krueger, & Vohs, 2003). For example, in their 10-year longitudinal study of university students, Salmela-Aro and Nurmi (2007) found that self-esteem predicted work engagement, thereby suggesting that resource gain processes can take place over a long time period. Research findings also show that high self-esteem may protect from burnout (Alarcon, Eschleman, & Bowling, 2009; Janssen et al., 1999; Kalimo, Pahkin, Mutanen, & Toppinen-Tanner, 2003). Together these studies suggest that a high level of self-esteem helps employees to cope successfully with stressors at work, and consequently, may lead to better health and well-being. Tellingly, to our knowledge, the link between self-esteem and *work ability* has not yet been examined, despite the fact that COR theory and self-enhancement theory provide a plausible theoretical framework for explaining the relationship between these variables. Thus, based on these three approaches, it can be assumed that employees who see themselves as worthy, significant and able as a person may also be more willing to put effort into their work tasks, and become fully involved in their work. As a result, their work ability will also be better than that of employees with lower levels of self-esteem. Therefore, we formulate the following hypothesis:

Hypothesis 2: Self-esteem at T1 will be positively related to work ability at T2 through work engagement at T2. In other words, work engagement will mediate the relationship between self-esteem and future work ability.

Work ability as a health-related resource in the JD-R model

Traditionally, in the JD-R model health-related indicators are considered to be outcomes of the health-impairment process. However, health-related outcomes may themselves be important resources that boost work engagement and consequently further improve health and well-being. In fact, The World Health Organization (WHO) defines health as a positive concept including physical, mental and social well-being, that is, “a resource for everyday life” rather than the objective of living (WHO, 1986). Thus, health can be conceptualized as a kind of capital in which individuals may invest in order to achieve positive future health outcomes (Williamson & Carr, 2009). In a similar vein, it can be argued that work ability is a health-related resource that is likely to be related to future well-being.

The Broaden-and-Build (BaB) theory of positive emotions (Fredrickson, 2001) provides a possible theoretical explanation for the mechanism that links work engagement and work ability. According to this theory, positive emotions broaden peoples’ thought-action repertoires, build their enduring personal resources and consequently lead to better well-being (see also Ouweneel, Le Blanc, Schaufeli, & Van Wijhe, 2012). Thus, based on the build hypotheses of the BaB theory, work engagement can be assumed to build health-related resources, such as work ability. In addition, and in line with COR theory, BaB theory proposes that emotions and well-being affect each other reciprocally (i.e. gain or upward spirals), supporting the assumption of mutually positive relationships between work ability and work engagement.

Empirically, there is convincing evidence supporting the role of work ability as a resource that may have beneficial effects on well-being and other health-related variables also in the long term. For example, Seitsamo et al. (2011) showed that work ability was a strong predictor of later-life health in a 28-year longitudinal study among Finnish municipal workers. Similarly, Ahlstrom, Grimby-Ekman, Hagberg, and Dellve (2010) found that work ability predicted future health among women working in human service organizations. Feldt, Hyvönen, Mäkikangas, Kinnunen, and Kokko (2009) in their turn showed that work ability of Finnish managers was related to job involvement and organizational commitment — both constructs that are closely related to work engagement.

Thus, based on BaB theory and on earlier research findings, we argue that work ability can be viewed as a health-related resource that fosters a high level of positive energy (vigour), strong identification (dedication) and strong focus (absorption) on one's work. Hence, we assume that good work ability is likely to influence work engagement, which, in its turn, may improve future work ability. Thus, we formulate our next hypothesis:

Hypothesis 3: Work ability at T1 will be positively related to work engagement at T2, which in its turn will be positively related to subsequent work ability at T2. In other words, work engagement will partially mediate the impact of work ability at T1 on work ability at T2.

The research model is graphically illustrated in Figure 1.

Method

Procedure and participants

The data is part of a questionnaire study among Finnish firefighters conducted in 1996, 1999 and 2009. In this study, we use the data from 1999 and in 2009 which include the variables of interest in the present study. The 10-year interval between data collections was determined by practical decisions and financial arrangements that the researchers could not influence. This long time interval offered the possibility to study the effect of the slow process of personal resource accumulation. In 1999, 1124 questionnaires were posted, and 72% (n = 794) were returned. At follow-up 10 years later, 68% (n = 721) returned the questionnaire. The research process is reported in detail elsewhere (Lusa et al., 2006; Lusa, Punakallio, & Luukkonen, 2011).

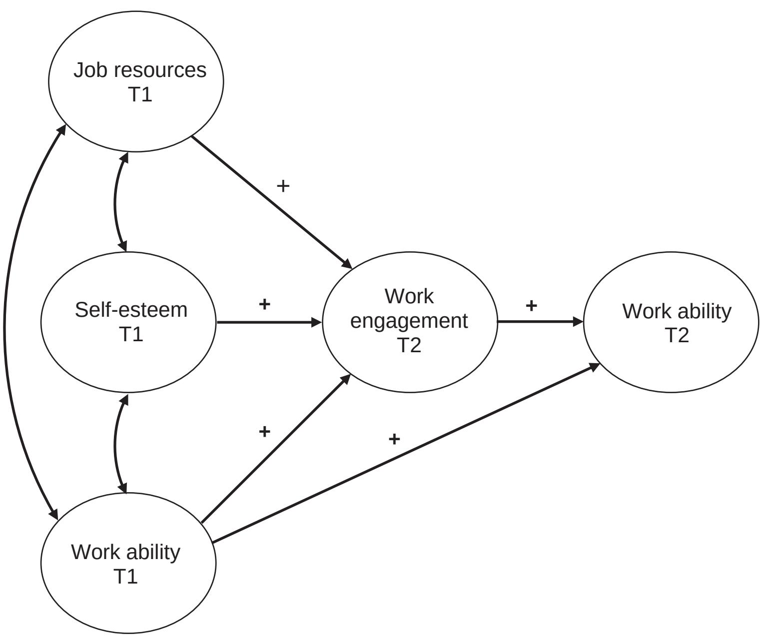

Figure 1. The theoretical model.

The study population of the current research consisted of professional operational firefighters who responded to the questionnaires in both 1999 (T1) and 2009 (T2), and were still employed in their profession (N = 403). All participants were men. At T2, the average age of the study population was 48.5 (range 35–62, SD = 5.4). The large majority (88%, n = 315) had firefighter qualifications, 29% (n = 105) had a sub-officer qualification and 10% (n = 35) had a fire chief qualification. Mean work experience in fire and rescue services was 25.3 years (range 3–39, SD = 5.8). Finally, at T2, 2% (n = 9) were not participating in operative tasks.

Of the respondents from 1999, 148 dropped out and did not participate in the study in 2009. Two-sample t-tests indicated that the dropouts were slightly older (mean age 39.9 vs. 38.5 years), had lower education (primary school education 29% vs. 18%) and had poorer work ability (mean score 7.5 vs. 8.1, score range 0–10) than those who responded at both times. By contrast, two-sample Wilcoxon tests revealed that the dropouts and the participants did *not* significantly differ in relation to self-esteem (mean value 34.85 vs. 34.31; score range 10–40), supervisory relations (mean value 3.78 vs. 3.73), interpersonal relations (mean value 3.95 vs. 3.97) or task resources (mean value 3.19 vs. 3.05; all three ranges 1–5).

Measurements

Job resources. The three job resources at T1 — supervisory relations, interpersonal relations and task resources — were adapted from the Occupational Stress Questionnaire, which is well validated in Finland (Elo, Leppänen, Lindström, & Ropponen, 1992). *Supervisory relations* included five items covering supervisory support, supervisory control and relationships between employees and supervisors. An example item is "Do you get support and help from your supervisor when needed?". *Interpersonal relations* consisted of four items: conflicts between employees, conflicts between younger and older workers, cooperation in one's work-unit and relationships between employees. An example item is "Do conflicts between employees affect your work?". *Task resources* included three items: decision making on issues concerning one's tasks, opportunities to use one's knowledge and skills at work and feedback on success in work tasks. An example item is "Can you use your knowledge and skills at work?". All job resource items were rated on a five-point scale ranging from 1 (*not at all/practically never*) to 5 (*very much*). A high score indicates a perception of supportive and co-operative supervision, positive interaction and co-operation between co-workers, task autonomy, opportunities for skill utilization and feedback.

Self-esteem. Self-esteem at T1 was measured using the Rosenberg Self-Esteem Scale (Rosenberg, 1965) consisting of 10 items. Rosenberg's self-report scale is one of the most widely used measures of self-esteem (Marsh, 1996). It includes both positive (e.g. "On the whole, I am satisfied with myself") and negative (e.g. "At times I think I am no good at all") items. All items were rated on a four-point scale ranging from 1 (*strongly disagree*) to 4 (*strongly agree*).

Work engagement. Work engagement at T2 was measured by the short version of the Utrecht Work Engagement Scale, UWES (Schaufeli, Bakker, & Salanova, 2006), consisting of nine items, with three sub-scales: vigour (e.g. "At my work, I feel bursting with energy"), dedication (e.g. "My job inspires me") and absorption (e.g. "I am immersed in my work"). Each of the dimensions was assessed using three items. The items were rated on a seven-point frequency-based scale ranging from 0 (*never*) to 6 (*daily*).

Work ability. Work ability at T1 and T2 was measured by one question with a scale from 0 to 10: "Assume that your work ability at its best has had a value of 10. How many points would you give your current work ability? (0 means that currently you cannot work at all)". This single-item question was derived from the Work Ability Index (WAI) questionnaire (Tuomi, Ilmarinen, Jahkola, Katajarinne, & Tulkki, 1998), a valid measure of work ability (van den Berg et al., 2009). Prior studies have indicated a strong association between the total WAI-score and the single-item indicator (e.g. Ahlstrom et al., 2010). In addition, both the total WAI and the single-item question have shown similar patterns of associations with diverse health-related outcomes (e.g. Ahlstrom et al., 2010). Thus, a single-item question of work ability is a good alternative to the rather complex measure of total WAI-index, and has been widely used in Finnish work life and health surveys (e.g. Kauppinen et al., 2010).

Score ranges for all variables are given in Table 1.

Data analysis

To test our hypotheses, we used structural equation modelling (SEM) techniques with maximum likelihood (ML) estimation and the AMOS 18.0 software package (Arbuckle, 2009). After testing the measurement model, we tested five different structural equation models. These were, firstly, the *hypothesized mediation model* (M1) in which work engagement fully mediates the relationships between job resources and self-esteem at T1 and work ability at T2, and partially mediates the relationship between work ability at T1 and work ability at T2; secondly, the *partial mediation model* (M2) which includes both the indirect (via engagement) and direct relationships between job resources and self-esteem at T1 and work ability at T2; thirdly, the *direct model* (M3) in which both job resources and self-esteem at T1 relate to work ability at T2 without the mediating role of work engagement, and work engagement relates to work ability at T2. In the fourth model, the *alternative direct model* (M4), job resources, self-esteem and work ability at T1 simultaneously relate to work engagement at T2 and work ability at T2. Thus, M4 includes three variables from T1 and two parallel outcomes at T2, and no mediators. Fifthly and finally, we tested *the alternative model* (M5) in which work ability at T1 is not related to work engagement, whereas the relationships between job resources and self-esteem at T1, and work ability at T2 are fully mediated by work engagement. Thus, this model was similar to the M1 except for removing the link between work ability at T1 and work engagement at T2.

The latent job resources variable was indicated by supervisory relations, interpersonal relations and task resources. After conducting an exploratory factor analysis, two scales

Table 1. Means, standard deviations and correlations between the study variables ($N = 403$).

Variables	Range	*M*	*SD*	1	2	3	4	5	6	7	8
1. Self-rated work ability T1	0–10	8.06	1.23	–							
2. Supervisory relations T1	1–5	3.78	.78	.15*	(.80)						
3. Interpersonal relations T1	1–5	3.95	.77	.10*	.49**	(.72)					
4. Task resources T1	1–5	3.19	.66	.08	.48**	.18**	(.68)				
5. Self-esteem T1	10–40	34.85	3.98	.19**	.23**	.16**	.26**	(.81)			
6. Vigour T2	0–6	3.90	1.48	.19**	.24**	.19**	.27**	.21**	(.89)		
7. Dedication T2	0–6	3.98	1.51	.17**	.18**	.17**	.26**	.23**	.90**	(.90)	
8. Absorption T2	0–6	3.30	1.58	.08	.16**	.16**	.23**	.12*	.78**	.81**	(.90)
9. Self-rated work ability T2	0–10	7.13	1.71	.33**	.18**	.05	.12*	.20**	.33**	.31**	.25**

Note: Cronbach's alphas are on the diagonal in parentheses.
$^*p < .05$; $^{**}p < .01$.

based on positive and negative items measuring self-esteem emerged, and they were used as indicators of the latent self-esteem factor. Work engagement was indicated by vigour, dedication and absorption scales. Work ability was based on a single-item indicator.

Model fit was evaluated using goodness-of-fit indices and conventional rules of thumb for their cut-offs. To test our hypotheses, we used the Chi-square (χ^2) test for goodness-of-fit, and compared the means of the chi-square difference test of different models. In addition, we examined the Root Mean Square Error of Approximation (RMSEA), the Comparative Fit Index (CFI) and the Tucker-Lewis Index (TLI). For RMSEA, values below .05 are indicative of a good fit, below .08 a satisfactory fit and values greater than .1 should lead to model rejection (Browne & Cudeck, 1993). For CFI and TLI, values greater than .90 indicate a good fit (Byrne, 2010). In addition, to compare the different models (M1 vs. M4), we used Akeike's Information Criterion (AIC). For AIC, smaller values represent a better model fit.

Finally, we performed a bootstrap on 2000 subsamples from the original data using the ML estimator with bias-corrected 95% confidence intervals for each of the parameter bootstrap estimates to test whether the pathways between the independent variables and the outcome variable via the mediator did, in fact, represent significant mediated relationships (see e.g. Hayes, 2009).

Results

Descriptive statistics

The means, standard deviations and correlations of the study variables are presented in Table 1. All correlations between the study variables were positive and therefore in the expected direction.

Measurement model

Before testing the hypothesized structural model, we estimated the so-called measurement model for all observed and unobserved variables simultaneously. The measurement model tests the measurement assumptions, relating the observed variables of the structural equation model to the latent factors while latent variables of the model are treated as common factors with no constraints on the correlations among the factors (Mulaik & James, 1995). Table 2 shows that the measurement model (MM) produced an acceptable fit to the data. The value of RMSEA fell below the limit of .08, whereas CFI and TLI exceeded the criterion of .90. All factor loadings of the latent variables exceeded the conventional minimum of .40, and the modification indices (MIs) did not indicate any cross-loadings or other needs for re-specifications in the model.

Testing the hypothesized model

Table 2 shows the fit indices and chi-square difference tests of the five models that were tested. The hypothesized mediation model (M1) fitted well to the data and significantly better than the direct effects model (M3) in which job resources and self-esteem at T1 only directly predicted work ability at T2 ($\Delta\chi^2 = 35.66$, $df = 1$, $p < .001$). However, there was no statistically significant difference between the hypothesized M1 and the partial mediation model (M2) in which job resources and self-esteem at T1 both directly, and

Table 2. Fit statistics for the study models and structural model comparison (N = 403).

Model	Description	χ^2	*df*	CFI	TLI	RMSEA	AIC	Model comparisons	$\Delta\chi^2$	Δdf
MM	Measurement model	71.91	27	.97	.94	.064	147.91			
M1	Hypothesized mediation model	76.33	29	.97	.94	.064	148.33			
M2	Partial mediation model	71.91	27	.97	.94	.064	147.91	M1 vs. M2	4.42 ns	2
M3	Direct effects model	111.99	30	.95	.90	.082	181.99	M1 vs. M3	35.66***	1
M4	Alternative direct effects model	94.92	28	.96	.91	.077	168.92	M1 vs. M4	18.59***	1
M5	Alternative model	80.97	30	.97	.94	.065	150.97	M1 vs. M5	4.64*	1

Notes: χ^2 = chi-square; *df* = degrees of freedom; CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; RMSEA = Root Mean Square Error of Approximation; AIC = Akaike′s Information Criterion; $\Delta\chi^2$ = chi-square difference; Δdf = degrees of freedom difference.
*$p < .05$; ***$p < .001$.

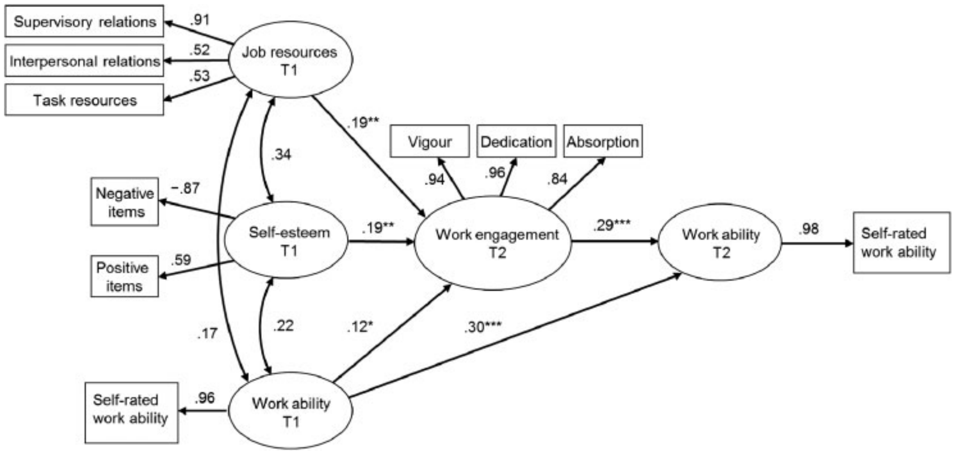

Figure 2. Final model of the mediating role of work engagement between job resources, self-esteem and work ability (N = 403). The circles represent unobserved latent factors (e.g. work ability), and squares observed variables (e.g. self-rated work ability).
Note: ***p < .001; **p < .01; *p < .05.

indirectly via engagement, predicted work ability at T2 (χ^2 = 4.42, Δdf = 2; ns). Since M2 did not improve the model fit compared with M1, the more parsimonious M1 was considered the better model.

To compare M1 with the competing non-nested and non-mediated M4 in which job resources, self-esteem and work ability at T1 only directly predicted both engagement and work ability at T2, we used Akaike's Information Criterion (AIC). AIC was larger for M4 (AIC = 168.92), thus representing a better fit for M1 (AIC = 148.33). Finally, we tested M1 against a similar model (M5), but without the path from work ability at T1 to engagement at T2. M1 fitted significantly better to the data than M5 (χ^2 = 4.64, Δdf = 1; p < .05), thus indicating the robustness of our finding that engagement partially mediates the impact of work ability at T1 on work ability at T2.

In the best-fitting model, M1 (see Figure 2), both job resources at T1 (β = .19, p < .01) and self-esteem at T1 (β = .19, p < .01) were positively related to work engagement at T2. Furthermore, work engagement at T2 was positively related to work ability at T2 (β = .29, p < .001). Work ability at T1 also predicted work ability at T2 10 years later (β = .30, p < .001), as well as work engagement at T2 (β = .12, p < .05). The hypothesized model explained 12% of the variance in work engagement at T2 and 21% of the variance in work ability at T2.

Finally, we used bootstrapping to test whether job resources, self-esteem and work ability at T1 yielded an indirect effect via work engagement on work ability at T2. Table 3 shows that all indirect effects were confirmed, thus supporting the mediating role of work engagement between the three T1 predictors (job resources, self-esteem and work ability) and work ability at T2.

Taken together, Hypotheses 1 and 2 on the mediating role of work engagement between job resources and work ability, and between self-esteem and work ability, respectively, were supported. In addition, Hypotheses 3 regarding the partial mediation of work engagement was also supported, as work ability at T1 had an indirect effect on work ability at T2, via work engagement.

Table 3. Indirect pathways using bootstrapping.

	Bootstrapping		BC 95% CI		
	Estimate	*SE*	Lower	Upper	*p*
Indirect effect x → m → y					
Job resources → work engagement → work ability T2	.062	.027	.018	.127	.001
Self-esteem → work engagement → work ability T2	.056	.027	.014	.124	.010
Work ability T1 → work engagement → work ability T2	.036	.019	.004	.081	.037

Note: Standardized coefficients. *SE* = standard error; BC = bias corrected; CI = confidence interval.

Discussion

The purpose of this study was to expand on previous studies on job and personal resources, work engagement and work ability within the Job Demands-Resources framework and using COR theory (Hobfoll, 1989, 2001), BaB theory (Fredrickson, 2001) and self-enhancement theory (Jones, 1973) as additional conceptual frameworks. More specifically, the impact of various kinds of resources (i.e. job, personal and health-related resources) on future work ability via work engagement was studied and all our study hypotheses were supported.

By using a 10-year longitudinal design, our results contribute to the literature in at least three ways. First, we found that work engagement fully mediated the relationship between job resources and self-esteem on work ability 10 years later, thus expanding the potential outcomes of the motivational process included in the JD-R model (Hypotheses 1 and 2, respectively). Second, our findings showed that work engagement and work ability were positively associated. This finding contributes significantly to the work ability literature, which has mainly focused on individual lifestyle- and work-related risk factors, and so far ignored the importance of motivational factors in explaining work ability (Ilmarinen, 2009). Third, our results show that work ability may be an important health-related resource itself, as it predicts work engagement 10 years later, which, in its turn, is positively associated with concurrent work ability (Hypothesis 3). The current study is one of the first on work ability that focuses not only on the antecedents of work ability but also on the positive consequences it may have (see also Feldt et al., 2009).

Job and personal resources and work ability

Our study showed that job and personal resources (self-esteem) may lead not only to positive organizational outcomes, such as better job performance (Salanova et al., 2005) and organizational commitment (Hakanen, Schaufeli et al., 2008), but also to improved work ability. Job resources had motivational potential as they were related to future work engagement, and consequently to work ability. Thus, jobs characterized by supportive conditions such as autonomous tasks, positive interactions between co-workers and support and positive feedback from one's supervisor, may foster flourishing and engaged employees who enjoy good work ability. These results support SDT (Deci & Ryan, 2000), which highlights the importance of social-contextual conditions that either enhance or hinder motivation at work. In our study, we measured task resources (autonomy, skill variety and feedback) and social resources (interpersonal and supervisory relations). Autonomy was related to participants' ability to exert control over their tasks; competence was related to their opportunities to use their skills and feedback; and supervisory relations and interpersonal relations were related to the relatedness need of the SDT, all of which are related to work engagement.

In addition, our results indicated that self-esteem as a personal resource plays a significant role in shaping work engagement, and via engagement also work ability in the long term, even when the impacts of baseline work ability and job resources are controlled for. In other words, the way in which people evaluate themselves affects how engaged they are, and how they assess their work ability. Thus, if a worker has a favourable attitude towards himself, considers himself worthy and respects himself, he is more likely to be enthusiastic about his work, and is more willing to put his energy into work than a colleague with low self-esteem. Moreover, he also has better work ability than his co-worker who evaluates himself or his job more negatively. As such, our results are consistent with the basic assumption of the JD-R model that highlights the relationships between personal resources, work engagement and positive work-related outcomes. In a similar vein, our results support the self-enhancement theory (Jones, 1973) that highlights the importance of self-esteem as a personal resource in promoting well-being. Our results tentatively support the COR theory's assumption of *resources caravans* (Hobfoll, 2001), that is, increasing resources (i.e. job resources and self-esteem) tend to generate new resources (i.e. work engagement and work ability), and thus form resource caravans.

The mediating role of work engagement between resources and work ability

Following the BaB theory of positive emotions (Fredrickson, 2001), we also examined the mediating role of work engagement between job and personal resources, and future work ability. It appeared, as expected, that the effects of job resources and self-esteem on work ability 10 years later were fully mediated by work engagement after controlling for baseline work ability. More specifically, increases in job resources and self-esteem at T1 were related to an increase in work engagement at T2, which, in its turn, was positively related to work ability at T2. In addition, it is noteworthy that work ability at T1 predicted work ability at T2 not only directly but also indirectly, via work engagement. Thus, our results show that work ability can be considered a health-related resource that may have beneficial effects on employee well-being also in the long term. More precisely, employees' work ability may function as a health-related resource that builds engagement, which, in its turn, may affect work ability positively, thus supporting BaB theory. It was not possible in the present study to directly test the positive gain cycle hypothesis between work engagement and work ability as suggested by both BaB theory and COR theory because work engagement was not measured at both time points (see also Salanova, Schaufeli, Xanthopoulou, & Bakker, 2010). However, our results suggest the possibility of such positive reciprocal relationships.

Limitations

Our study has some limitations that should be noted. First, it was based on self-report measures, which may cause systematic measurement errors (common method variance). However, we conducted Harman's single factor test as suggested by Podsakoff, MacKenzie, Lee, and Podsakoff (2003). The test showed that common method variance did not pose a problem because the one-factor solution did not account for the majority of the covariance among the measures. Moreover, the longitudinal design used in the current study may diminish the risk of common method bias (Doty & Glick, 1998). Nevertheless, future research would benefit from applying more objective indicators of job resources, and particularly of work ability.

Second, as we only studied job and personal resources at T1 and work engagement at T2, no causal relationship between, for example, work engagement and work ability could be determined. However, as the competing model, in which work engagement and work ability at T2 were parallel dependent variables, fitted less well than the hypothesized model, we may conclude that our model with work engagement as a mediator is a plausible one. Nevertheless, future research should investigate the effect of (and possible reciprocal relationships between) work engagement on work ability, as well as a full panel design including job and personal resources measured at all study points.

Third, the 10-year time lag used in our study may not be optimal for testing the model, as other processes such as organizational changes may have influenced the effect of independent variables on the outcomes. In general, such long time lags may lead to an underestimation of the true causal relationship between study variables (Zapf, Dormann, & Frese, 1996). However, despite the changes in the organizational structure in Finnish fire departments, the work environments and colleagues for the most part remained the same. Related to the third limitation, the effect sizes were small, albeit significant. However, the significant relationships between the study variables even over the 10-year time lag are, in fact, indicative of the robustness of the findings. In addition, even relatively small effect sizes may be salient in predicting health and well-being of employees (Ford, Woolridge, Vipanchi, Kakar, & Strahan, 2014). Nevertheless, in future studies, the research model should be tested using a shorter time lag, a full panel design and with a larger sample size, as suggested by Ford et al. (2014).

Fourth, the rather high number of dropouts may be considered a limitation. However, the differences between participants and dropouts were either non-significant or minimal. In addition, it can be expected that for the most part dropout was due to retirement because of the low retirement age among Finnish firefighters (i.e. 55 years). A stepwise increase in actual retirement age has only recently occurred in Finland; however, early retirement schemes and personal retirement arrangements (under 55 years of age) are still possible routes for retirement. Therefore, the dropout from the sample can be regarded as normal and not causing any particular bias to the results.

Finally, our study focused on only one profession: firefighters. Although some caution is needed in interpreting our results, we believe that they can be extended to other occupational sectors. First, similar evidence exists of the positive impact of work engagement on various occupational sectors and countries (e.g. Hakanen et al., 2006). Second, as job and personal resources positively affected work ability via work engagement even in a highly physically demanding job, i.e. firefighting, we assume that the same effects are also likely to be found in other occupational sectors. However, this remains to be tested.

Conclusions

Our 10-year longitudinal study showed the existence of a health-related mechanism in the motivational process of the JD-R model. Both job resources and personal resources were related to future work engagement, which, in its turn was related to work ability. Moreover, we found that work engagement partially mediated the effect of baseline work ability on work ability 10 years later. As such, our findings contribute to the work ability literature, which has mostly neglected its motivational aspects. Our results indicate that work engagement, supported by resourceful jobs and positive self-esteem, plays an important role in maintaining and promoting work ability, and consequently, possibly also in decreasing employees' intentions towards early retirement.

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ORIGINAL ARTICLE

Sleep disturbances predict long-term changes in low back pain among Finnish firefighters: 13-year follow-up study

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Abstract
Purpose To investigate the prevalence of low back pain among Finnish firefighters and to examine whether sleep disturbances predict membership of low back pain trajectories.
Methods In this prospective study, 360 actively working firefighters responded to a questionnaire in 1996, 1999 and 2009. The outcome variables were radiating and local low back pain during the preceding year. Using logistic regression modeling, the likelihood of membership of pain trajectories was predicted by sleep disturbances at baseline.
Results During the 13-year follow-up, the prevalence of radiating low back pain increased from 16 to 29 % ($p < 0.0001$) and that of local low back pain from 28 to 40 % ($p < 0.001$). The following trajectories were identified: "pain free," "recovering," "new pain," "fluctuating" and "chronic." More than one-fifth of the participants belonged to the new pain trajectory as regards both pain types, 6 % of the participants belonged to the chronic radiating and 12 % to the chronic local low back pain trajectory. Those with sleep disturbances at baseline had a 2.4-fold risk (adjusted OR 2.4; 95 % CI 1.2–4.7) of belonging to the new pain or chronic radiating pain cluster compared to pain-free participants.
Conclusions This is the first prospective study to show that low back symptoms are common and persistent among firefighters and that sleep disturbances strongly predict membership of a radiating pain trajectory. Occupational health and safety personnel, as well as the firefighters themselves, should recognize sleep problems early enough in order to prevent back pain and its development into chronic pain.

Keywords Back disorders · Longitudinal studies · Sleep · Firefighters

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Introduction

Firefighting is a universal profession, with rather similar work features across countries, i.e., extinguishing fires, performing rescue operations and often also medical first aid. Firefighting work has considerable physical as well as psychological demands, causing high loading of both the body and mind. However, firefighters' health problems, especially musculoskeletal disorders, have rarely been reported in epidemiological studies. (Sluiter and Frings-Dresen 2007).

Early retirement due to disability is frequent among firefighters. In Finland, for example, little <70 % of operative firefighters are able to work until their normal retirement age (63–68 years). In 2008–2010, the mean age of disability retirement among Finnish firefighters' was 53. The most common reasons for early retirement are musculoskeletal (43 %), mental (14 %) and cardiovascular (14 %) disorders. The most common medical diagnoses (16 % of all diagnoses) for early retirement are related to low back (e.g., degeneration of lumbar disk). (A Koski-Pirilä, The Local Government Pensions Institution, personal communication, 2011).

The number of full-time workers in the fire and rescue sector (including firefighters and paramedics/ambulance drivers) in Finland is approximately 5,000. In addition, about 14,000 part-time employees and voluntary fire brigade members are available for emergency situations (Ministry of the Interior of Finland 2006). Each year in Finland, some 85,000 emergency operations are carried out by firefighters, and this number has doubled over the last 10 years. In addition, approximately 200,000 urgent ambulance call-outs are also answered by firefighters in Finland each year (Ministry of the Interior of Finland 2006).

Most of the above-mentioned firefighting and rescue tasks require extremely good musculoskeletal health. Increasing problems in daily work tasks at fire stations, due to firefighters' musculoskeletal problems, may occur among the aging workforce in particular. There is an obvious need to gain a better understanding of the long-term course of low back pain among firefighters and of factors affecting this. From occupational health personnel's perspective, more information on symptoms and their risk factors is essential in order to better treat and prevent these problems. Firefighters would benefit from such information: They could learn what to expect in terms of symptoms, how pain may impact their work and why interventions may be needed.

Sleep problems are a potential risk factor in the development of pain symptoms among firefighters. In addition to physically strenuous work, firefighters are also exposed to abnormally long work shifts (often 24-h). A recent study showed that firefighters' sleep problems reduce physical well-being (Carey et al. 2011). Sleep problems have also been established as a risk factor for pain, especially back pain, among workers other than firefighters. In a study among blue- and white-collar Finnish workers, sleep disturbances independently doubled the risk of developing low back pain during a 1-year follow-up (Miranda et al. 2008).

The aim of this 13-year follow-up study was to:

1. investigate the prevalence of radiating and local low back pain among Finnish firefighters at baseline and during the 3- and 13-year follow-up.
2. examine whether sleep disturbances at baseline predict the likelihood of belonging to a pain trajectory.

Methods

Study design

The data were based on a 3- and 13-year follow-up study of the health, and physical and mental capacity of Finnish professional firefighters (Lusa et al. 2006; Punakallio et al. 2012). The study consisted of repeated extensive questionnaires as well as objective measurements of the health and physical capacity of firefighters. This paper is based on these self-administered questionnaires. The study was approved by the Ethics Committee of the HUS Hospital District, and was performed according to the ethical principles of the Declaration of Helsinki.

At baseline in 1996 (T0), 1 124 participants out of 3 512 professional operative male firefighters were selected from all over Finland by stratified sampling (Punakallio et al. 1999). The baseline sample was representative of Finnish firefighters.

Outcomes

Radiating and local low back pain

Information on radiating and local low back pain both at baseline and follow-ups was elicited using a question based on a validated Nordic questionnaire that has high repeatability and sensitivity (Kuorinka et al. 1987). The question was: "Estimate for how many days altogether you have had radiating (or local) low back pain during the last 12 months."

The answers were classed into two categories: "0 = no pain" (pain on 0–7 days or not at all), "1 = pain" (including pain on 8–30 days, pain >30 days but not daily, or daily). Our study inquired about radiating and local low back pain separately, as have other previous studies (for example Miranda et al. 2002). We assumed that there is a set number of distinct courses of radiating and local low back pain and that the participants could be grouped into distinct trajectories, with each participant belonging to a certain trajectory.

Predictors and covariates

The variables treated as predictors were chosen on the basis of the literature and pre-analysis of the data (correlation analysis of the predictors and outcome variables). The main predictor of interest was sleep disturbances, elicited through a self-administered questionnaire in 1996. Sleep disturbances were considered mild if the firefighter reported either not sleeping well during the last 3 months or having been extremely tired during the daytime for at least 3–5 days a week; and severe if they reported both (Partinen and Gislason 1995). This measure has been used in many epidemiological studies (e.g., Jansson-Fröjmark and Lindblom 2008; Linton 2004), and is considered fairly reliable (e.g., Biering-Sørensen et al. 1994).

Covariates

The variables included as covariates in the analysis were as follows: age, pain other than low back pain, work accidents, smoking, physical workload and psychosocial job demands. Age was classified as <30, 30–40 and >40 years. Pain other than low back pain, information on which was elicited by the Nordic Questionnaire (Kuorinka et al. 1987) (neck, shoulder, upper-arm, hip and knee), was classed into two categories: "0 = no pain" (pain on 0–7 days or not at all), "1 = pain" (pain on 8–30 days, pain >30 days but not daily, or daily) and a sum variable was formed. Work accidents were elicited by the question: "Over the last 3 years, have you suffered accidents or minor injuries at work? If so, how many?" Answers were categorized into 0, 1, 2 or >2. Smoking was inquired about by two different questions: "Have you ever smoked regularly?" (yes/no). "Do you still smoke?" (yes/no). We categorized the participants into never smokers, ex-smokers and current smokers. Physical workload was measured using four items adapted from Viikari-Juntura et al. (1996). The questions were as follows: "How many hours on average per shift do you work on your knees, on your hunches, squatting or crawling?" (1 = not at all, 2 < 1/2 h, 3 = 1/2–1 h, 4 =>1 h), "How many hours on average per shift do you work with your back bent forward?" (1 = <1/2 h, 2 = 1/2–1 h, 3 = 1–2 h, 4 =>2 h) and "How much do you estimate that you work with your back twisted during a regular shift?" (1 = not at all, 2 = a little, 3 = moderately, 4 = a lot). A sum variable was formed from the items (3–12) and categorized into three classes: <6, 6–7 and > 7.

Psychosocial job demands consisted of four items based on and modified from the questions of earlier studies and the analysis by Airila et al. (2012): responsibility of job, fear of failure at work, excessive demands of work (Tuomi et al. 1991) and lack of supervisor's support (Elo et al. 1992). Items were rated on a five-point scale (0 = none, 1 = few, 2 = some, 3 = rather many, 4 = very many). We formed a variable of the items (0–16): none (0), few (1–4), some (5–8) and rather many/very many (9–16). We also asked about work experience ("How many years have you been working in the rescue department?") and working hours ("What kind of working hours do you do: 24-h shift work, other kind of shift work, regular daytime work, other?").

Data analysis

First, the prevalence of low back pain, the distribution of the participants into the different pain trajectories, and the characteristics of the trajectories were analyzed by applying cross-tabulations (chi-square tests) and *T* tests. Associations between variables were studied by Pearson's and Spearman's correlation analysis.

We tried to form trajectories by two-step cluster analysis, available in SPSS Statistics 17.0. In addition, we tried to identify trajectories using the modeling strategies available in statistical software package SAS version 9.2 (SAS Institute Inc. 2008). We also continued to form many kinds of pain course combinations for radiating and local low back pain according to our own hypothesis.

The likelihood of belonging to a certain pain trajectory was predicted by sleep disturbances at baseline using logistic regression modeling (proportional odds model). The models were formed so that in the first model only sleep disturbances were the predictor. Secondly, we added age to the model. Then, sleep disturbances adjusted by age and covariate formed their own separate models, one at a time. Finally, the last model was formed by backward stepwise logistic regression analysis. First, sleep disturbances and all the main covariates were entered into the same model. We continued by eliminating variables one at a time until all the remaining variables were significant at the critical level of 0.05. Odds ratios and their 95 % confidence intervals were calculated. In the outcome variable (pain trajectories), the reference group was those who belonged to the pain-free trajectory. The statistical analyses were carried out using the SAS statistical software package, version 9.2 (SAS Institute Inc. 2008).

Results

Participants

Altogether 849 (76 %), 794 (72 %) and 721 (68 %) firefighters answered in 1996 (T0), 1999 (T1) and 2009 (T2), respectively, after two reminders. Of the 2009 sample, 63 % (n = 451) were still working in the fire and rescue sector. The most common reasons for drop-out were old-age retirement (18 %, n = 125), disability pension (7 %, n = 48), change of job (4 %, n = 28) and sick leave (3 %, n = 23).

The sample of this study was formed from the participants who responded to each questionnaire and worked actively in firefighting and rescue tasks during the follow-up. The final sample comprised 360 male firefighters. Their mean age at baseline was 36 ± 5.4 years. The number of non-respondents after baseline was 465. They were older (41.6 ± 9.0) than the participants of this study (Table 1); more than half of them (59 %) were over 40 years of age. They had longer work experience, did shift work more often, and more often had mild or severe sleep problems and musculoskeletal pain other than back pain. They also seemed to have higher psychosocial job demands and were more often smokers. No differences were found in physical workload, work accidents or the prevalence of radiating or local low back pain compared to the respondents.

Table 1 Characteristics of follow-up cohort and non-respondents (retired/drop-outs)

Characteristics in 1996	Follow-up cohort (actively working participants, $n = 360$)	Retired or dropout due to non-response ($n = 465$)
Age (years), mean ± SD	35.7 ± 5.4	41.6 ± 9.0
Age group [*n* (%)]		
<30	46 (13)	60 (13)
30–40	219 (61)	130 (28)
>40	95 (26)	275 (59)
Work experience (years) mean ± SD	12.3 ± 5.3	17.3 + 8.2
Working hours [*n* (%)]		
24-h shift work	265 (74)	375 (81)
Other kind of shift work	62 (17)	58 (13)
Regular daytime work	24 (7)	22 (5)
Other	8 (2)	7 (1)
Sleep disturbances [*n* (%)]		
None	208 (58)	235 (51)
Mild	137 (38)	194 (42)
Severe	14 (4)	33 (7)
Radiating low back pain [*n* (%)]	53 (16)	77 (19)
Local low back pain [*n* (%)]	95 (28)	111 (26)
Musculoskeletal pain in body parts other than back [*n* (%)]	207 (58)	265 (58)
Smoking [*n* (%)]		
Never smoker	74 (21)	75 (16)
Ex-smoker	117 (33)	112 (24)
Current smoker	168 (47)	277 (60)
Physical workload sum index (0–12) [*n* (%)]		
<6	121 (34)	132 (29)
6–7	140 (39)	186 (42)
8–12	97 (27)	129 (29)
Number of work accidents during last 3 years [*n* (%)]		
0	43 (20)	47 (19)
1	61 (28)	74 (29)
2	51 (24)	61 (24)
>2	60 (28)	71 (28)
Psychosocial job demands sum index (0–16) [*n* (%)]		
None (0)	108 (30)	113 (24)
Few (1–4)	193 (54)	226 (49)
Some (5–8)	48 (13)	101 (22)
Many/very many (9–16)	11 (3)	22 (5)

Radiating and local low back pain

Table 2 shows the proportion of the participants who reported having had radiating pain in the low back on more than 7 days during the preceding 12 months. The prevalence of radiating low back pain increased during the 3-year follow-up from 16 to 23 % ($p < 0.05$) and rose during the 13-year follow-up to 29 % ($p < 0.0001$). The prevalence of local low back pain was higher than radiating low back pain at baseline (28 %) and increased significantly during the 13-year follow-up, reaching 40 % at the end of the follow-up.

Trajectories of radiating and local low back pain

After meticulous analysis, we found five trajectories that best described the courses of radiating and local low back pain. These five trajectories, based on our own pre-analysis and hypothesis, were as follows: pain free, recovering, new pain, fluctuating and chronic (Fig. 1). We also formed

Table 2 Prevalence of radiating and local low back pain of actively working firefighters in 1996, 1999 and 2009 ($n = 360$) and significant differences between years, p

Musculoskeletal pain	Prevalence						p	p
	1996		1999		2009		1996	1996
	%	n	%	n	%	n	1999	2009
Radiating low back pain	16	(53)	23	(76)	29	(100)	<0.05	<0.0001
Local low back pain	28	(95)	28	(95)	40	(137)	ns	<0.001

five trajectories by the two-step cluster analysis available in SPSS Statistics 17.0, but in this sample they did not function as well as our own division of the trajectories. The main differences occurred in the cases in which the pain category changed during the follow-up time (recovering, new pain and fluctuating). The pain-free and chronic groups were the same in both analyses. The two-step cluster analysis also placed some of the cases of new pain and fluctuating pain, as well as recovering and fluctuating pain, together. In addition, the program automatically formed only four clusters, and we think that these clusters were problematic in the same way as described above. Therefore, we considered that our own trajectories best described the courses of pain during the 13-year follow-up. In the models, both outcome variables were categorized into three categories: 1: pain free, 2: recovering or fluctuating, 3: new pain or chronic. The reason for combining recovering and fluctuating into one category (in the analysis) is that at one study point at least, the participants (in this trajectory) were pain free. How this differed to the new pain and chronic trajectory is that the trend of the pain course was not so clear.

Many of the respondents belonged to the pain-free trajectory: of radiating low back pain more than half (54 %), and of local low back pain, 41 %. However, almost one-fourth (24 %) of the participants belonged to the new pain trajectory of local low back pain and about one-fifth (21 %) to the new pain trajectory of radiating pain. In the chronic pain trajectory, 6 % of the participants had radiating and 12 % of the participants had local low back pain. The proportions of the recovering trajectory were 8 % radiating and 11 % local low back pain (Table 3).

Table 4 shows the proportion of firefighters in each of the five radiating low back pain trajectories and their corresponding characteristics. The radiating low back pain trajectories did not differ significantly with respect to age, smoking and psychosocial job demands. In all trajectories, the majority of firefighters were 30–40-year-olds at baseline. However, in the pain-free trajectory, one-fifth of firefighters were under 30, whereas in the chronic trajectory, 35 % were over 40.

Sleep disturbances at baseline seemed to be more prevalent in all the other trajectories except the pain-free trajectory of radiating low back pain ($p = 0.0044$) (Table 4). Musculoskeletal pain in other body parts at baseline seemed to be less common among firefighters belonging to the pain-free trajectory of radiating low back pain ($p = 0.0013$) than to the other trajectories. Moreover, there were fewer smokers (36 %) in the pain-free cluster. The proportion of smokers was highest

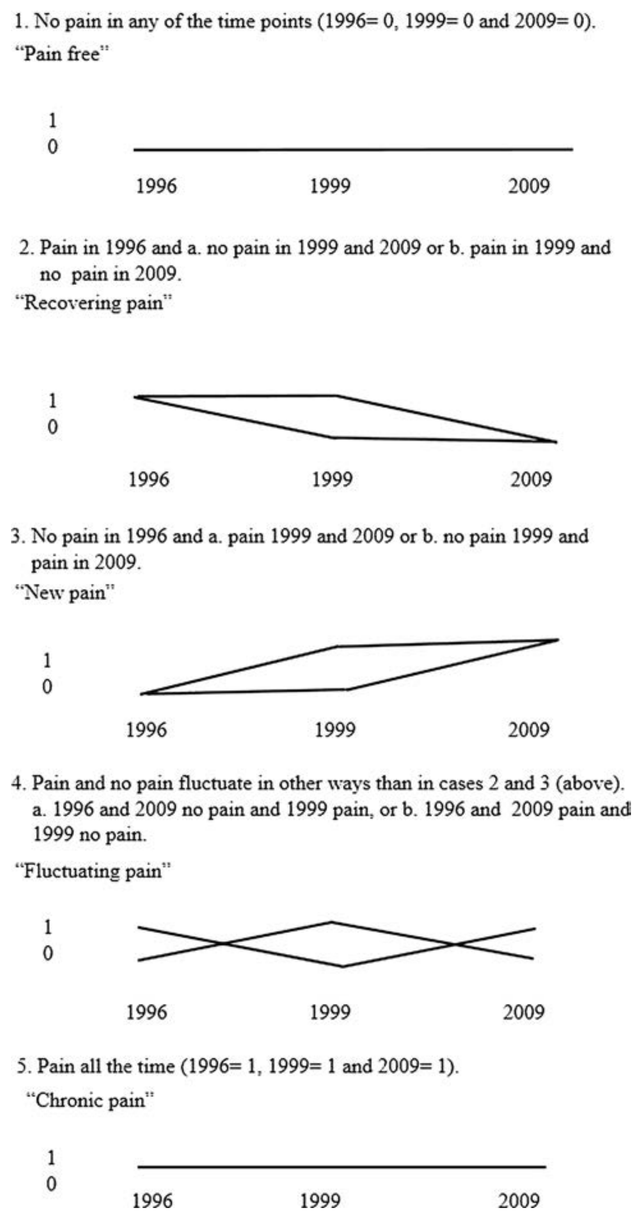

Fig. 1 Description of the pain trajectories formed in this study

Table 3 Proportion of actively working firefighters belonging to different trajectories of radiating and local low back pain in 1996, 1999 and 2009 ($n = 360$)

Musculoskeletal pain	Trajectory									
	Pain free		Recovering		New pain		Fluctuating		Chronic	
	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*
Radiating low back pain	54	(148)	8	(21)	21	(56)	11	(30)	6	(17)
Local low back pain	41	(126)	11	(33)	24	(73)	12	(35)	12	(36)

Table 4 Characteristics of five trajectories of radiating low back pain and significant differences between trajectories, *p*

Characteristics in 1996	Pain free $n = 148$ (54 %)	Recovering $n = 21$ (8 %)	New pain $n = 56$ (21 %)	Fluctuating $n = 30$ (11 %)	Chronic $n = 17$ (6 %)	*p*
Age (years) mean ± SD	35 ± 6	37 ± 6	36 ± 5	37 ± 5	37 ± 4	
Age group [*n* (%)]						
<30	29 (20)	2 (10)	4 (7)	2 (7)	0 (0)	
30–40	85 (57)	11 (52)	37 (66)	18 (60)	11 (65)	
>40	34 (23)	8 (38)	15 (27)	10 (33)	6 (35)	
Sleep disturbances [*n* (%)]						0.0044
None	96 (65)	9 (43)	20 (36)	3 (43)	8 (47)	
Mild	49 (33)	9 (43)	33 (59)	15 (50)	8 (47)	
Severe	3 (2)	3 (14)	3 (5)	2 (7)	1 (6)	
Musculoskeletal pain in other body parts [*n* (%)]	70 (56)	13 (81)	39 (83)	19 (79)	11 (85)	0.0013
Smoking [*n* (%)]						
Never smoker	40 (27)	5 (24)	8 (14)	4 (14)	1 (6)	
Ex-smoker	54 (36)	5 (24)	15 (27)	9 (31)	6 (35)	
Current smoker	54 (36)	11 (52)	33 (59)	16 (55)	10 (59)	
Physical workload sum index (0–12) [*n* (%)]						0.007
<6	54 (37)	6 (29)	14 (25)	4 (13)	4 (24)	
6–7	58 (39)	12 (57)	27 (49)	9 (30)	6 (35)	
8–12	35 (24)	3 (14)	14 (25)	17 (57)	7 (41)	
Number of work accidents during last 3 years [*n* (%)]						0.002
0	22 (27)	4 (27)	5 (13)	0 (0)	2 (18)	
1	24 (30)	2 (13)	12 (30)	6 (27)	0 (0)	
2	24 (30)	3 (20)	10 (25)	7 (32)	1 (9)	
>2	11 (14)	6 (40)	13 (33)	9 (41)	8 (73)	
Job demands sum index (0–16) [*n* (%)]						
None (0)	44 (30)	5 (24)	16 (29)	8 (27)	3 (18)	
Few (1–4)	87 (59)	10 (48)	30 (54)	15 (50)	10 (59)	
Some (5–8)	13 (9)	5 (24)	8 (14)	6 (20)	3 (18)	
Many/very many (9–16)	4 (3)	1 (5)	2 (4)	1 (3)	1(6)	

in the new pain and chronic trajectory of radiating low back pain (59 and 54 %) ($p = 0.0725$) in 1996. Physical workload seemed to be highest in the fluctuating cluster ($p = 0.007$) and number of accidents in the chronic cluster ($p = 0.002$).

As regards local low back pain, the trajectories did not differ significantly from each other. The mean age of the firefighters in the chronic and fluctuating trajectory was lower (34 years) than that in the other trajectories (35–37 years). It was also lower than the mean age of the chronic trajectory of radiating low back pain (37 years).

Predictive models for membership of pain trajectories

Those firefighters who reported having sleep disturbances at baseline were three times more likely to belong to the new pain or chronic trajectory than to the pain-free

Table 5 Odds ratios (OR) and 95 % confidence intervals for predictor, predictor adjusted for age and adjusted for age and covariates one at a time, as well as final model, predicting membership of low back pain trajectory

Factors in 1996	Risk of belonging to trajectory OR (95 % CI)			
	Radiating low back pain		Local low back pain	
	Fluctuating/recovering versus pain free	New pain/chronic versus pain free	Fluctuating/recovering versus pain free	New pain/chronic versus pain free
Sleep disturbance	2.4 (1.3–4.7)	3.0 (1.7–5.3)	1.5 (0.8–2.7)	1.5 (0.9–2.5)
Adjusted by age				
Sleep disturbance	2.3 (1.2–4.4)	2.9 (1.6–5.1)	1.6 (0.9–3.0)	1.6 (0.9–2.7)
Sleep disturbance	1.5 (0.7–3.2)	2.5 (1.3–4.9)	1.3 (0.6–2.7)	1.7 (0.9–3.1)
and musculoskeletal pain in other body parts	3.0 (1.3–7.1)	3.5 (1.6–7.5)	1.4 (0.7–2.9)	1.7 (0.9–3.2)
Sleep disturbance	2.5 (1.0–6.2)	2.1 (1.0–4.6)	1.2 (0.5–2.7)	1.2 (0.6–2.4)
and number of work accidents during last 3 years	1.6 (1.1–2.5)	1.5 (1.1–2.2)	1.3 (0.9–1.9)	1.4 (1.0–2.0)
Sleep disturbance	2.1 (1.1–4.1)	2.7 (1.5–4.9)	1.6 (0.9–3.0)	1.5 (0.9–2.6)
and smoking	1.4 (0.9–2.2)	1.8 (1.2–2.6)	0.9 (0.6–1.3)	1.2 (0.9–1.8)
Sleep disturbance	2.2 (1.1–4.2)	2.9 (1.6–5.2)	1.6 (0.8–2.9)	1.5 (0.9–2.6)
and physical work load	1.7 (1.1–2.7)	1.3 (0.9–1.9)	1.0 (0.7–1.5)	1.2 (0.8–1.7)
Sleep disturbance	2.2 (1.1–4.2)	2.8 (1.6–5.1)	1.6 (0.9–3.0)	1.5 (0.9–2.6)
and job demands	1.2 (0.8–1.9)	1.1 (0.7–2.7)	1.0 (0.6–1.5)	1.1 (0.8–1.6)
Final model adjusted for age				
Sleep disturbance	1.5 (0.7–3.1)	2.4 (1.2–4.7)	0.4 (0.2–0.8)	0.5 (0.2–1.1)
Musculoskeletal pain in other body parts	3.2 (1.3–7.7)	3.8 (1.7–8.4)	0.3 (0.2–0.7)	1.0 (0.4–2.6)
Smoking	1.5 (0.9–2.4)	1.9 (1.2–2.9)	0.5 (0.3–0.9)	0.7 (0.4–1.3)

Logistic regression analysis, significant at the level of $p < 0.05$

trajectory of radiating low back pain (Table 5). The risk remained almost as high when the model was adjusted for age. Furthermore, after adding musculoskeletal pain in other body parts to the model, the risk was still 2.5-fold. Pain in other body parts (at baseline) also strongly predicted the risk of belonging to the new pain or chronic trajectory, OR 3.5 (CI 1.6–7.5), and to the fluctuating/recovering trajectory, OR 3.0 (CI 1.3–7.1). Sleep disturbances were also a strong predictor for belonging to the fluctuating/recovering cluster: They presented a 2.4-fold risk, and when adjusted for age, a 2.3-fold risk. The association was no longer significant after adjusting for pain in other body parts.

After adjusting for sleep disturbances by age and other main covariates (work accidents, smoking, physical workload, job demands) one at a time, the risk of belonging to the new pain or chronic trajectory still remained over twice that of belonging to the pain-free trajectory, as did belonging to the fluctuating or recovering trajectory compared to membership of the pain-free trajectory.

In the final model, we added sleep disturbances and all co-factors (age, smoking, physical workload and psychosocial job demands) together. The predictive value of sleep disturbances remained significant. The risk of belonging to the new/chronic radiating low back pain trajectory was 2.4-fold (CI 1.2–4.7) compared to that of belonging to the pain-free trajectory. Musculoskeletal pain also remained a significant co-factor: OR 3.8 (CI 1.7–8.4) for new pain/chronic and OR: 3.2 (CI 1.3–7.7) for the fluctuating/recovering trajectory compared to the pain-free trajectory. In addition, smoking almost doubled the risk of new/chronic pain (CI 1.2–2.9).

We also formed the same models for local low back pain, but none of the chosen factors predicted belonging to the trajectories of local low back pain.

Discussion

This study showed that low back pain is a common and persistent health problem among firefighters. Sleep disturbance was a strong predictor of persistent or onset of radiating low back pain. The development of local pain was not, however, affected by sleep.

We were able to establish five different trajectories of radiating and local low back pain during the 13-year follow-up: pain free, recovering, new pain, fluctuating and chronic.

Firefighters are a select group of professionals characterized by good physical fitness and health. Their fitness requirements are exceptionally high compared to those of many other professions due to the physically and mentally demanding work tasks related to firefighting. Somewhat unexpectedly, we found that a representative sample of actively working Finnish firefighters reported radiating and local low back pain as often as other Finnish male workers of corresponding age. Almost half (46 %) of the firefighters had radiating low back pain at some time point during the follow-up period. This is in line with the results of Heistaro et al. (2007), who found that 41 % of Finnish male workers have had radiating low back pain at some phase during their life.

Every fourth firefighter experienced new radiating low back pain and every fifth local low back pain during follow-up. Our results are, however, influenced by the healthy worker effect, i.e., selection bias due to disability retirement and dropout. It is likely that the reason for dropout or early retirement has in some cases been low back problems, since about one-fifth of the dropouts reported radiating and one-fourth local low back pain at baseline when they were still active in the workforce (Table 4). It is therefore likely that the true long-term prevalence of back pain among firefighters is considerably higher than that captured in our study and other similar types of prospective studies based of self-assessment.

However, due to the universal nature of firefighting, there is an emerging need for scientific studies on the health effects of the job. Only a few published studies exist on firefighters' musculoskeletal disorders. Sluiter and Frings-Dresen (2007) reported that in the Netherlands, 20 % of firefighters younger than 25 reported low back complaints over a 6-month time period. Among firefighters aged 50–54, the prevalence was 39 %. This age-related increase is in line with our results. In the Dutch study, those who reported having low back problems in addition to shoulder and knee problems, and who were older than 49, also reported decreased work ability due to these complaints. In another Dutch study by Bos et al. (2004), almost half (47 %) of Dutch firefighters (mean age 39 years) reported disabilities resulting from back complaints. Also in Finland, according to the statistics of the Local Government Pensions Institution, musculoskeletal problems (especially low back) are the most common reason for early retirement among Finnish firefighters. (A Koski-Pirilä, The Local Government Pensions Institution, personal communication, 2011).

We found five different trajectories of low back pain among Finnish firefighters: pain free, recovering, new, fluctuating and chronic musculoskeletal pain. With respect to radiating low back pain, these trajectories were statistically significantly distinguished by sleep disturbances, pain in other body parts, physical workload and work accidents. In the case of local low back pain, the factors did not distinguish the trajectories, which may be due to the non-specificity of this type of pain compared to radiating low back pain. Radiating low back pain is also a more severe type of pain than local low back pain.

The pathways of low back pain in primary care have been studied by Dunn et al. (2006). They concluded that their classification into four pathways of pain ("recovering," "persistent mild," "fluctuating" and "severe chronic"), by latent class analysis, provides a detailed alternative for improving understanding of the course of back pain. The pathways showed significant differences in disability, psychological status and work absence, and they were well maintained throughout a 1-year follow-up. Another study reported that most people remained in a similar trajectory in a 7-year follow-up (Wiesel 2011).

Tamcan et al. (2010) also investigated the course of low back pain in the general population using latent class analysis over a 1-year period. They identified four clusters of low back pain: "fluctuating," "mild persistent," "moderately persistent" and "severe persistent"; but did not have a "recovering" cluster in their study. Their four clusters differed significantly in relation to age and dependence on help. They also found that a considerable proportion of patients in the fluctuating group changed classifications. None of these studies investigated the predictors of group membership, as we did.

In earlier studies, pain pathways have been formed by latent cluster analysis and the studies have had various follow-ups, usually short in duration, i.e., 1 year (Dunn et al. 2006; Tamcan et al. 2010). In our study, the pain measurements and classifications were to a great extent different and the follow-up longer. Dunn et al. (2006) concluded that the optimal number of trajectories is either four or six for longitudinal latent class analysis. We also tried a two-step cluster analysis, which is available in SPSS, and this gave two different classifications: four and five clusters. However, they did not function as well as our own division of the clusters. The main differences were in the recovering, new and fluctuating trajectories, whereas the pain-free and chronic groups were the same. The two-step cluster analysis combined the cases of new and fluctuating, as well as recovering and fluctuating. We preferred to keep recovering separate; the numbers of participants in the recovering cluster was high enough (n = 22 % in radiating low back pain and 33 % in local low back pain). We considered our own clusters to better describe the course of the pain during the 13-year follow-up.

Many epidemiological studies have found that sleep disturbances increase the risk of further back pain and its development into chronic pain. Sleep problems also predict the need for hospital care, work disability, and pain in body parts other than the back (Eriksen et al. 2001; Hoogendoorn et al. 2001; Haig et al. 2006; Kaila-Kangas et al. 2006; Auvinen et al. 2010). Although there is evidence that pain leads to sleep disturbances, several studies also show that sleep disturbances may cause pain (for example Smith et al. 2009). For example, in a laboratory setting, it was found that the lack of REM-sleep in particular increased pain sensitivity (Lautenbacher et al. 2006; Roehrs et al. 2006). Possible mechanisms for the sleep–pain relationship are inflammation, changes in hormonal functions, metabolism and tissue regeneration (Lautenbacher et al. 2006; Roehrs et al. 2006). Sleep deprivation may also cause an increase in body weight, which in turn can lead to back pain. Sleep deprivation may also disturb the regulation of brain functions and increase chaos in the brain, affecting pain sensitivity (Irwin et al. 2006; Schmid et al. 2007).

In our study, sleep disturbances at baseline strongly predicted chronic or onset of radiating low back pain during the 13-year follow-up. The predictive power of sleep disturbances remained high after adjustment for age and further adjustment for physical workload and psychosocial job demands. Musculoskeletal pain in other body parts was a strong co-factor in the model. Since we have no information on the time before baseline, we cannot rule out the possibility that pain in body parts other than the low back may have preceded sleep disturbances. It is also possible that earlier back pain (before the first study) might have preceded sleep disturbances. There might also be reverse causality in the chronic trajectory, because participants in this group already suffered pain at baseline. Unfortunately, the number of participants did not allow us to study the predictive power of sleep disturbances in the baseline pain-free group or to compare it with that of the group with pain. Furthermore, we wanted to study the courses of pain. In our population, the predictive power of sleep disturbances remained significant after adjustment for shift work. This may be due to the fact that almost all the participants did shift work.

It is essential to understand the relationship between sleep disturbances and back pain, because many firefighters have sleep problems. In this sample of Finnish firefighters, 42 % reported sleep disturbances at baseline (and of the drop-outs 49 %). Many other studies on firefighters have indicated that sleep problems are also associated with other types of health problems, such as decreased psychosomatic well-being, vigilance, alertness and mental performance, as well as increased fatigue and depression (Lusa et al. 2002; Elliot and Kuehl 2007; Carey et al. 2011).

Among firefighters, sleep patterns may be disturbed by long work shifts and alarms. For example in Finland, the most common shift is the 24-h shift (Carey et al. 2011). The treatment of sleep problems in security occupations is challenging. The use of sleeping pills, for example, is not recommended due to the physically and mentally demanding nature of the work. For preventing sleep and other health-related problems early enough, environmental- and individual-based interventions should be planned for firefighters.

Study strengths and limitations

The main strengths of our study lie in its longitudinal design. The 13-year study period with three measurement points allowed us to study the courses of pain over time and claim for at least some causality, although we could not completely exclude the possibility of reverse causality. We also had to take into account the fact that the periods between the study points were quite long (3 and 10 years), and we do not necessarily know all that happened during this time. At baseline, this study population was a representative sample of Finnish firefighters. The response rates to baseline and follow-up surveys were good. As we only included in this study the participants who responded on all three occasions, the number of dropouts was high. In addition to the health-based selection from the workforce, almost one-fifth of the dropouts retired normally on old-age pension, because of the low retirement age among Finnish firefighters during the study period, i.e., 55 years, and early retirement schemes and personal retirement arrangements (under 55 years of age) which are still possible routes for retirement. Therefore, dropout from the sample can be regarded as partly normal. However, our results are influenced by the healthy worker effect, which means that they are unlikely to overestimate the associations between sleep disturbances and low back pain.

This study was based on self-report measures, which may cause an overestimation of the associations between study variables due to common method variance bias. However, such bias is less likely in longitudinal studies (Doty and Glick, 1998). Furthermore, our data were mainly collected through widely used, valid and reliable questionnaires (Kuorinka et al. 1987; Tuomi et al. 1991; Elo et al. 1992; Linton 2004; Biering-Sørensen et al. 1994; Jansson-Fröjmark and Lindblom 2008). Information on symptoms was collected using the validated Nordic questionnaire, which is widely used, has high repeatability and sensitivity, and is considered an international standard (Kuorinka et al. 1987). A cutoff of above 7 days of pain and the 12-month time period of the follow-up are also commonly used criteria in musculoskeletal disorder studies (Miranda et al. 2002). In addition, the questions on sleep disturbances are widely used in epidemiological studies (Partinen and Gislason 1995; Miranda et al. 2008). They take into account both not sleeping well and tiredness after waking up. Most of the questions concerning the other covariates have been validated (Viikari-Juntura et al.

1996). A limitation concerning the questions was that the length of memory time varied.

Our study focused on only one profession and gender, male firefighters; and thus, the results can be generalized to other occupations and women only with caution. The sample at baseline, however, was comprehensively selected and was a good representation of Finnish firefighters.

Conclusion

In conclusion, the results of this study help us better understand the different courses of back pain over a long time period. It also shows, for the first time among actively working firefighters, that sleep disturbances need to be taken into account in the prevention and treatment of back pain. In health examinations, musculoskeletal pain in all body parts should be monitored sufficiently early, together with sleep disturbances, so that the development of chronic pain could be prevented through individual-based or environmental interventions. Sleep guidance should be an essential part of workplace health promotion.

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Conflict of interest The authors declare no conflicts of interest.

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Physiological Stress Associated with Structural Firefighting Observed in Professional Firefighters

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FOREWORD

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My fire service career spans 30 years; and I have lost track of the thousands of firefighters that I have had a chance to meet. Yet, when the name of Dr. Jim Brown is mentioned in a conversation, I am struck by the image of a person who has never pulled a hose line or climbed a ladder. But this man however will be remembered as one of the true leaders of the fire service. From our first meeting I was impressed by his sincere interest in the well being of firefighters. It was a meeting that I will never forget.

Fast-forward to 2007, Dr. Brown received approval of a firefighter health and safety grant. This grant finally gave the fire service something we desperately need; accurate data on the physical strain a firefighter endures. For six months Dr. Brown and his associates lived, ate and slept with firefighters. This research group compiled data on the physical effects of firefighters at working fires and EMS incidents, from sleeping at night to nights with no sleep, from the coldest nights of winter to the warmest days of summer.

After a few months into the study, I met with Dr. Brown and he provided information and data from the study. I became even more fascinated by what this report will mean to the fire service today and in the future. This report will give the leaders of the fire service the needed data to tackle the prevalent issues to firefighters such as physical stress on the body, sleep disorders and the necessity of rehab at emergency incidents. Using this data as a road map, the fire service can make a commitment to address the needs and improve the quality and longevity of the firefighter.

Therefore, it is a pleasure and a unique honor to be able to write a forward of this report, and it is my honor to be associated with this project. Also, as a third generation firefighter and the father of a firefighter it is my duty to constantly work with visionaries like Dr. Brown to improve conditions for all those that follow me.

Robin Nicoson

Chief of Safety

Indianapolis Fire Dept

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INTRODUCTION

INTRODUCTION

U.S. Department of Labor statistics indicate that firefighters are three times more likely to die on the job than any other occupation (43). Improvements in tactics and equipment have reduced the overall number of on-duty deaths. However, the number of annual firefighter deaths in the US remains high. Recently released data indicates that 104 U.S. firefighters lost their lives on duty during 2006 (3) while 115 were lost in 2005 (2). Of the deaths reported during 2005, more than half (54%) can be attributed to stress or overexertion including heart attacks, cerebrovascular events (stroke) or other types of cardio-respiratory system collapse (heat exhaustion etc.). These 2005 stress and overexertion deaths rates echo data reported over the last 25+ years (1). With the reduction of fatalities related to other causes, the prevalence of cardiovascular-related deaths has emerged as a significant problem for the fire service. On average, 50% of on-duty firefighter deaths are due to cardiovascular system failure (1).

The fire service responded to this high incidence of heart attack and cardiovascular-related fatalities with programs to reduce this type of line of duty death (LODD). The National Fire Protection Association (NFPA) has established guidelines governing health and fitness characteristics of firefighters and firefighter candidates. NFPA 1582, outlines mechanisms of health-related physical fitness assessment and physical training programs to improve fitness. The stated goal of these standards is to reduce LODD by improving the general health of firefighters. Indeed, improving the overall health of firefighters would significantly improve their fire ground survivability, especially those with underlying cardiovascular disease or cardiovascular disease risk factors. However, recent investigation of the physical stress associated with firefighter training activities suggests these goals may fall short of protecting firefighters from the risk of physical overexertion. Data collected during a 2005 study by Maryland Fire & Rescue Institute (MFRI), indicate that firefighter fitness level and pre-participation hydration status were the primary determinants of the cardiovascular stress experienced by firefighters (2). More importantly, physiology of firefighters described as having average fitness levels responded in a manner similar to those of low fitness levels during training activities. The study also pointed out that firefighters demonstrating high levels of physical fitness experienced much less physical stress during the same training activities. In addition, that study pointed out that regardless of fitness level, firefighters demonstrating even moderate levels of dehydration experienced severe levels of cardiovascular stress. These findings suggest that firefighting activity may represent greater levels of physical stress than previously expected and may be in excess of what standing fitness goals may alleviate. Recent efforts to monitor training activities have provided much needed insight into the stress of firefighting activities. However, little or no useful physiological data exists from real fire ground operations. Realization of this fact has led to recent initiatives to secure such information.

A workshop convened by the National Institute of Standards and Technology (NIST) identified firefighter physiology as a significant need in the fire service (44). More recently, the National Fallen Firefighter Foundation (NFFF) conducted a symposium to identify and prioritize research needs within the fire service (45). The workshop report identified firefighter physiological responses to heat stress and acute physiological responses to emergency call as high priority areas of research need. The study described herein undertook this challenge by measuring firefighter physiology on the real world fire ground.

Study Goals

A primary goal of this project was to investigate the physical rigor of real fire scene work. Fire scene work tasks may differ widely with respect to their cardiovascular and respiratory stress. Therefore, the project sought to illustrate normative data for multiple fire ground tasks including fire attack, search & rescue, exterior ventilation, and overhaul activities.

The presence of an independent observer (scientist) on the fire ground provided opportunity to describe the fire scene environment under which firefighter physiology data was being collected. Subsequent analysis allowed the identification of the fire scene factors having the greatest impact on firefighter physiology. Further, these factors were also prioritized with respect to their relative importance.

The full access to firefighters provided by the study also allowed some investigation into the psychological aspects of answering emergency call. Specifically, a comparison of emotional stress and anxiety between on and off duty life may provide some insight in to a source of firefighter risk for development of heart disease.

Research Partnerships

Accomplishing the goals of this project required the cooperation of many organizations. A research consortium was established among the primary organizations involved. However, the ultimate responsibility for success or failure of the project lay with the individual firefighters invited to participate. It was the role of the following institutions to provide support for participating firefighters.

Indiana University Firefighter Health & Safety Research

The Firefighter Health & Safety Research program is component of Indiana University's Harold H. Morris Human Performance Laboratory. It is governed by the Department of Kinesiology and the School of Health, Physical Education & Recreation. The program was organized to specifically to support faculty research interests in the health and safety of First Responder populations. The mission of the program is to support the reduction of firefighter line of duty deaths through applied research.

Indianapolis Fire Department

Indianapolis is a rapidly growing, outstanding community that is recognized as a great place to work and live. Hailed as the 12th largest city in America and home to a diverse population, the city attracts millions of visitors annually. Indianapolis is proud to offer its citizens a world class Fire Department. IFD, with over 150 years of proud tradition, is made up of men and women with diverse cultural backgrounds, each who have taken the oath to protect and serve the citizens of Indianapolis.

Indianapolis Firefighters work closely with the residents and businesses through fire prevention and safety education programs to make their city as safe as possible. The Indianapolis Fire Department is made up of over 940 sworn members and a 50-member civilian support team. The IFD fire service district covers 198 square miles of downtown Indianapolis and surrounding areas.

With a strong history of being progressive thinking forward in areas of firefighter health and safety, IFD provided an ideal organization to participate in the study. Health status and work capacity of IFD firefighters are regularly tested. This provided a population of highly trained, medically supervised career professional firefighters.

Indianapolis Metropolitan Professional Firefighters Association

The International Association of Fire Fighters granted Indianapolis Firefighters their Charter in October of 1934. Today, Indianapolis (Marion County) and its citizens are served by 17 different fire departments are represented by Local 416. Currently Local 416 membership includes over 2,300 firefighters, paramedics, dispatchers and retirees. Local 416 fosters and encourages a high degree of skill, and efficiency, the cultivation of friendship among its members and the support of moral, intellectual and economic development of its membership.

Endorsement of the project by Local 416 leadership facilitated the recruitment of firefighters for the research project. A union representative accompanied the scientific team to fire stations during recruitment. Their presence put potential subjects at ease and helped remove any suspicions or concerns the firefighters had. In addition, Local 416 worked closely with the research team to provide support and to facilitate compensation of participating firefighters.

Indiana Homeland Security

The Indiana Department of Homeland Security, in collaboration with citizens, government, and private entities, will achieve the common purpose of preventing, protecting against, responding to and recovering from man-made or natural threats and events to people, property, and the economy. The IDHS Division of Fire and Building Safety investigates suspicious fires, promotes prevention, administers building plan review, enforces fire and building safety codes in all public buildings, regulates and coordinates emergency services, emergency medical services and hazardous material response and oversees and conducts inspections of child care facilities, boilers and pressure vessels, elevators and amusements. The IDHS Office of the State Fire Marshal represented Indiana's volunteer firefighters throughout the study. Upon completion of the study, this office facilitated distribution of pertinent information to Indiana's volunteer firefighting force.

Embedded Scientists

A unique aspect of the study was the need for continuous scientific observation of on-duty firefighters. IFD rotates three shifts of firefighters on a 24-hour on / 48-hour off duty cycle. To accomplish continuous monitoring, a scientist was assigned to each IFD shift. The scientist lived in the fire station and accompanied firefighters on all fire runs. Scientists were trained in fire station etiquette and fire ground safety procedures. Scientists worked under the command of the station's shift officer and Incident Commander at the station and on fire scenes respectively. Scientists were uniformed for identification both in the fire station and on the fire ground. Scientist uniforms distinguished them from IFD personnel but made them easily recognizable as fire ground qualified.

Delimitation of the Study

The study is bound by the architectural and geographical character of Indianapolis, Indiana. In order to obtain sufficient fire scene data, a high-fire-volume region of the city of Indianapolis was chosen for the study site. Architecturally, this area of the city is populated by single and double wood framed residences. Typically, these structures are less than 2000 ft^2. From a geographical stand point, Indianapolis enjoys a fairly moderate climate. Accordingly, Indianapolis does not provide exposure to extremes of weather, hot or cold. The study was conducted during the winter months in order to avoid the complication of atmospheric heat stress. The goal of the study was to assess, as much as possible, the physical aspects of fire fighting work. The avoidance of added heat stress provides a more focused examination on that factor. This will allow us to identify firefighter and fire scene variables impacting the physiological responses of firefighters.

Unfortunately, these delimiting factors may limit the applicability of the findings to areas outside Indianapolis or central Indiana. In order to address the impact of weather and other atmospheric extremes (elevation), a future study is planned to assess the same physiological stress on firefighters in areas of the country that will provide access to these weather extremes. In addition, US cities providing access to other architectural character will also be utilized in that future study.

Finally, the study represents physiological responses of a firefighting corps that is known to be well trained technically and monitored by a medical program adhering to NFPA standards (31). This group of firefighters was chosen because it may be used as a model corps. Other, less fit firefighters should not expect to respond in a similar manner.

Scope of the Report

This document reports the physiological aspects of structural firefighting and the psychological impact of answering emergency call as outlined in the associated application for funding. The use of continuous physiological monitoring to capture data required the report resulted in the capture of much information not associated with fire scenes. Every heartbeat, breath, and footstep is captured throughout the duty shift. As a result, many other aspects of firefighter physiology were captured and should be evaluated despite being outside the scope of the original project proposal. This report is limited to reporting the goals of the original funded protocol. Other physiological issues identified during the course of the study will be pursued in subsequent peer-reviewed scientific publications. These subsequent reports will cover such topics as sleep dysfunction, Heart rate variability analysis for determination of sympathetic / parasympathetic balance, respiratory mechanics associated with positive pressure SCBA systems, and a comparison of physical activity levels on and off duty.

DEFINITION OF TERMS

Physiology

HR: Heart Rate in beats per minute

HR_{MAX}: Maximal heart rate as determined by the formula: $HR_{MAX} = (220-Age)$

Alarm HR_{MAX}: Maximal HR attained during the first 90 seconds after alarm.

$\%HR_{MAX}$: Percentage of a person's predicted maximal heart rate

Alarm $\%HR_{MAX}$: Percentage of predicted maximal HR following alarm

PHR*t*: Time to reach peak heart rate

V_E: Minute ventilation or volume of air moved by the lungs in one minute expressed in Liters of air per minute.

Tidal Volume: Volume of air moved with each breath expressed in milliliters

Breathing Freq: Frequency with which breaths are taken expressed in breaths per minute.

Vo_{2MAX}: Maximal rate Oxygen consumption, generally considered a measure of cardiovascular fitness (expressed in milliliters of Oxygen consumed per kilogram of body weight per minute).

EPOC: Excess Post-exercise Oxygen Consumption. Consumption of Oxygen in excess of that dictated by physical demand after work ceases.

AccM: Physical activity score derived by integration of rectified outputs of all accelerometer axes. Output samples are converted to positive values and added together to give a score representative of total body movement.

SBP: Systolic Blood Pressure in millime ters of Mercury

DBP: Diastolic Blood Pressure expressed in millimeters of Mercury

FIREFIGHTING

Alarm: 90 second period of time following the sounding of audible alarm to alert personnel.

Ingress: Period of time from exiting the fire station until arrival at fire scene.

Fire Attack: Hose line work executed by an En gine company to extinguish fire

Ventilation: Vertical or horizontal ventilation of a burning structure generally executed by a the outside team of a Ladder company

SAR: Search and rescue operations executed by the outside team of a Ladder company or by a Rescue Squad crew

Ladder: Fire apparatus staffed by a company of four firefighters and carrying a rear-mounted aerial ladder, several ground ladders, extrication and EMS gear.

Engine: Fire apparatus staffed by a company of four firefighters and carrying 1.5" & 2.0" hand lines, 3" & 5" supply lines, 250 gallons of water, and basic& advanced life support EMS gear.

Squad: Fire apparatus staffed by two firefighters and carrying basic and advanced life-support EMS gear along with extrication equipment.

TSU: Tactical Service Unit:. Apparatus dispatched on working incidents to support fire scene operations.

PPV Fan: Positive Pressure Ventilation: Fan used to clear smoke from a structure..

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Duration: Elapsed time to complete a single phase of fire scene work.

BRIEF REVIEW OF LITERATURE

BRIEF REVIEW OF LITERATURE

Firefighters face many hazards, including chemical exposure, thermal injury, and trauma. From 1995 to 2007, there were 1,345 on-duty firefighter fatalities (1-3). What is surprising, however, is that over 44% of these deaths were classified as sudden cardiac death (1-3). Volunteer firefighters (VFF) fall victim to sudden cardiac death at a disproportionate rate when compared to professional firefighters (PFF). Of the 440 sudden cardiac death victims from 1995 to 2004, nearly 70% were VFF (1). Of the victims over 60 years of age, 93% were VFF (1). It was proposed that this might reflect the tendency of VFF to remain active beyond retirement age. From 2001 to 2005, over 80% of the victims were over the age of 40 and over half were over the age of 50 (4). In a review of all on-duty firefighter deaths between 1994 and 2004, 32% were associated with fire suppression duties, 31% involved firefighters responding to or returning from alarms, 13% occurred during training activities, and the remaining 24% occurred during other firefighting duties, such emergency medical services and administrative tasks (5). The author suggests the risk of sudden cardiac death during fire suppression may be increased due to inadequate physical fitness, the presence of cardiovascular risk factors, and existing medical conditions (5). Possible explanations for the increased risk of sudden cardiac death in firefighters include psychological stressors, heat stress, smoke and chemical exposure, and high physical demands (6-7). It is unclear which and to what degree occupational and personal risk factors increase the risk of sudden cardiac death.

The prevalence of cardiovascular disease risk factors in firefighters has been investigated (8-14). Obesity is known to be a significant risk factor for cardiovascular disease and is associated with adverse health conditions. In a study by Soteriades et al. (8), baseline and 5-year follow-up measurements of body mass index (BMI) and blood pressure were evaluated in municipal firefighters. Of those studied 53% were found to be overweight and 34.9% were obese upon entering the study. After 5 years, obesity prevalence increased significantly to 39.7%. Obese individuals were also more likely to have hypertension at both baseline and follow-up. A separate study conducted by Clark et al. (9) observed similar results. This study also reported significant increases in diastolic blood pressure, total cholesterol and triglyceride levels with increasing BMI (9).

Elevated cholesterol levels are another known cardiovascular risk factor. Hypercholesterolemia has been observed in 69.4% of firefighters as reported by Soteriades et al. (10). In this study, firefighters with higher cholesterol levels were more likely to be older, obese, and have higher triglyceride levels. Likewise, Licciardone et al. (11) reported an age-related increase in body weight, total cholesterol, and blood pressure. Byczek et al. (12) found the prevalence of obesity, hypertension, and high total cholesterol in male firefighters to be higher than those in U.S. adult men. There is limited research investigating the presence of cardiovascular disease risk factors in VFF (13). Swank and colleagues reported similar prevalence of all modifiable cardiovascular disease risk factors between VFF and the general population. In general, an individual's risk for cardiovascular disease increases with the presence of multiple risk factors, advancing age, or elevations in risk factor severity (14).

The presence of cardiovascular risk factors, especially obesity, is known to limit the performance of firefighters (15). Extra fat adversely affects job performance (16) and hinders heat dissipation, which creates strain upon the heart. Overall, the upper body fat distribution typically found in men is associated with higher blood pressure, higher serum glucose and cholesterol levels, and coronary heart disease (17). The high prevalence of cardiovascular risk factors found in firefighters may contribute to a higher risk of sudden cardiac death and adversely affect firefighting performance.

Little research has examined the physiological requirements of firefighting in order to characterize the physical demands and identify fitness characteristics needed for successful job performance (116, 18-29). Firefighting is known to induce significant demands on cardiovascular functioning as well as require substantial physical strength for prolonged periods (18-20). Firefighters endure long periods of inactivity followed by high degrees of physical stress (6). During the immediate response to an alarm, firefighters experience significant increases in heart rate (21). Upon arrival at the fire scene, firefighters work at levels above 80% of their maximal heart rate (HR_{max}) for a substantial period of time completing fire suppression duties (18). However, quantifying workload from heart rate alone is difficult due to the influence of heat stress, decreased oxygen, and increased carbon dioxide levels.

Maximal oxygen consumption ($VO_{2\ max}$) has consistently been identified as an important factor in the association of firefighting demands and physiological requirements (22-23). Lemon and Hermiston observed that firefighters complete simulated duty tasks at 60-80% $VO_{2\ max}$ even without the external stress of the fire scene (22). Duncan et al. (24) reported that the workload imposed in a hot environment by the properties of the protective clothing significantly increases the oxygen requirements. In addition, wearing a self-contained breathing apparatus (SCBA) has been observed to change firefighters' breathing pattern and increase oxygen consumption during exercise (25). Thus, firefighting requires individuals to perform at high levels for substantial periods of time. Yet, it is still difficult to determine the physical stress experienced by firefighters during on-duty fire suppression because the research is consisted mainly of firefighting simulation studies and there is an unaccounted psychological component.

Because firefighting is one of the most physically demanding occupations, it is recommended that firefighters possess a high level of fitness to

ensure the safety of the general public and themselves (16, 26). It is important to realize, though, that all recommendations have been based on research conducted using simulated firefighting activities. Most investigators recommend a minimum $VO_{2\ max}$ between 39.6 $ml \cdot kg^{-1} \cdot min^{-1}$ and 48.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (16, 26). Sothmann et al. (27) found that individuals with $VO_{2\ max}$ values below 33.5 $ml \cdot kg^{-1} \cdot min^{-1}$ were unable to complete a standard fire suppression protocol. Lemon and Hermiston concluded that firefighters must possess high levels of anaerobic power (28). High levels of upper and lower body strength and muscular endurance have also been recommended for increased job performance and reduced risk of injury (16, 29). However, previous research has reported that the fitness characteristics of professional firefighters are comparable to the normal range of U.S. adult men with sedentary lifestyles (28). A sample of PFF were found to have a mean $VO_{2\ max}$ value of 40.57 $ml \cdot kg^{-1} \cdot min^{-1}$ (28). VFF were found to be overweight and have an average VO_2 max value of 31.5 $ml \cdot kg^{-1} \cdot min^{-1}$, with 75% of those tested falling between 20 and 39 $ml \cdot kg^{-1} \cdot min^{-1}$ (19). In addition, the decline

in $VO_{2\,max}$ of both PFF and VFF with age is similar to the general population (19, 28).

In 2004, 16 Firefighter Life Safety Initiatives were identified to aid the US Fire Administration's goal of reducing firefighter fatalities by 25% within the following 5 years and 50% within the following 10 years (30). Experts concluded there is a need to develop national medical, training, and physical fitness standards based upon the duties each firefighter is expected to perform. However, before any standards can be developed, the physical demands need to be determined, as well as which physical fitness and fire scene characteristics affect the required workload. A model may then be built to predict the interaction of relevant variables and determine which firefighters are at a higher risk of injury due to overexertion.

While the National Fire Protection Association recommends fire department medical examinations and specific fitness for duty criteria (31), more than 70% of the fire departments do not have programs to maintain firefighter fitness and health (1). Most do not require firefighters to exercise regularly or undergo periodic medical examinations even though exercise intervention programs have shown to decrease the incidence of accidents and increase job performance (32).

Although there has been beneficial research regarding the physiological response to firefighting, all but two of the previously referenced articles were conducted during fire simulations and training. While simulation and training studies provide insight, they do not translate well to real-life scenarios due to the ever-changing environment and emotional response. Thus, it is still unclear how the cardiorespiratory system responds to the demands of real-world on-duty fire suppression, specifically in regards to each firefighter's role at the fire scene. Additionally, the most important occupational and fitness characteristics for predicting the physiological response to firefighting have yet to be determined.

STUDY METHODS

STUDY METHODOLOGY

Subject Recruitment & Informed Consent

In cooperation with the Indianapolis Fire Department (IFD), fire stations historically working the greatest number of structural fires were identified as possible study sites. The architectural character of the station's primary response area and the station's ability to provide physical space for researchers were considered. Two stations offering the most advantageous profiles were selected for recruitment. Firefighters staffing these stations and meeting eligibility requirements were extended an invitation to participate by the research team.
A subject's eligibility to participate was their designation as "fit for duty" duty as defined by the Indianapolis Fire Department. To determine fitness for duty, IFD firefighters undergo annual physical fitness evaluations that meet or exceed NFPA standard 1583. All medical examination procedures outline in NFP 1583 Chapter 2, Section 2-1 are addressed annually. In addition, all IFD firefighters undergo a graded exercise test (with a 12-lead ECG) annually. Finally, IFD firefighters must submit to and pass a Firefighter-specific work capacity test annually in order to be declared fit for duty.

Invitation was made in person at the fire station. Interested firefighters were provided with study information and given sufficient time to consider participating in the study. Fifty seven (57) subjects volunteered to participate in the study. Informed Consent was provided by each subject as dictated by the Indiana University Institutional Review Board (IRB).

Orientation and Physical Assessment

Once identified, subjects were orientated with study procedures and key study personnel. Additionally, the physiological monitoring system was introduced. Subjects were fitted with the LifeShirt™(LS) device and instructed as to its operation. To engage the LS device, firefighters removed their shirts and placed ECG electrodes at the upper left and upper right torsos as well as the lower left torso. With electrodes in place, subjects donned the LS vest and closed the inner of two zippers. Through holes provided, ECG electrodes were connected to a data collection cable and respiratory inductive plethysmography (RIP) bands embedded in the vest were connected to the cable.

This data cable (which also houses a two-axial accelerometer) was then connected to the LS data recorder. Subjects then stood erect, powered up the system and placed the LS recorder in a provided holding pouch. With the system operational, the device was calibrated by repeated re-breathing from a disposable, 800 milliliter calibration bag provided by the manufacturer. The active system was then worn under standard firehouse duty garments for the remainder of the duty shift.

Subjects completed a demographic and health history questionnaire (Appendix C), as well as relevant information concerning the firefighter's career (time in service, rank and position, etc.). After completing these questionnaires, the physical assessment commenced within the fire station apparatus bay. The assessment consisted of resting measures of heart rate and blood pressure, accomplished by palpation and auscultation respectively. Body composition was determined using a three-site, gender-specific Skinfold analysis (Jackson, Pollack, 1980). Aerobic capacity was assessed using the Queens College Step Test. For this test, subjects step on and off a 16.25 inch box at a paced rate. Subjects stepped continuously for three minutes and then stood quietly for another minute. Heart rate at 20 seconds post test was obtained from the LifeShirt data and used to estimate aerobic capacity (VO_2max) for each individual. Post test heart rates will be entered into one of the following, gender specific equations to estimate Vo_{2MAX}:

Male: Vo_{2MAX} ($ml \cdot kg^{-1}\text{-}min^{-1}$) = 111.33 – (0.42 x HR)

Female: Vo_{2MAX} ($ml \cdot kg\text{-}1 \cdot min\text{-}1$) = 65.91 – (0.1847 x HR)

Where: HR = Mean heart rate during the period 5 seconds to 20 seconds after exercise

Handgrip strength was assessed in both hands using a handgrip dynamometer (Lafayette Instruments). Subjects were asked to squeeze the handle of a dynamometer, exerting a maximal effort. Each subject performed three trials with the greatest measure of strength recorded as hand grip strength. General muscular strength and endurance were assessed by 1-minute pushup and curl-up tests respectively. Flexibility was assessed with a standard sit-and-reach box.

Data Collection

General Firefighter Protocol

Subjects donned the LS system at the beginning of each duty shift and wore the system throughout their 24-hour shift for a six month period. All LS data clocks were synchronized with the fire department dispatch clock upon start up. Subjects provided information concerning their duty assignment for the shift including station, apparatus, and apparatus seat). When necessary (showering, damage to the system etc.), subjects removed and replaced system components to maintain data stream. Research team personnel were available to assist with equipment problems or answer subject questions at all times. At each shift change event, research team personnel were present to assist in equipment turnaround and to retrieve collected data.

Fire Scene Data Collection

A member of the science team accompanied dispatched companies on all fire runs. When fire runs were designated working structural fire inci-

dents scientists recorded fire-ground descriptive information as well as operational milestone time periods pertinent to the study. This data was subsequently uploaded to the study database. In addition to the physiological and operational data, a helmet mounted thermal imaging video camera (Fire Warrior, Total Fire Croup, Dayton, OH) was utilized to record firefighter physical activity inside burning structures. Weather data including temperature, wind speed, and relative humidity were recorded on the fire scene using a handheld weather monitor (Cole-Parmer, Model R-99756-17). Scientist wore small bullet cameras (Oregon Scientific, Portland, OR) mounted on their helmets and fire apparatus to provide a video record of the fire scene. Scientists were issued departmental radios to monitor fire ground activity. Scientist-collected video and radio communications were used to assure capture of subject fire ground activity.

Data Handling: Physiology and Fire Scene Data

Research team personnel collected all firefighter-based data at the end of each duty shift. Fire scene descriptive data was immediately uploaded to the database and stored for later analysis. Firefighter physiology data was uploaded from individual LS data cards using LS-accompanying VivoLogic® software. Events expected to result in significant physiologic response were identified from the fire department dispatch log and fire-scene collected data. Using these event markers, firefighter physiology data was extracted from the full data set for subsequent analysis.

One minute averages of data were extracted from the time-series data based upon an event log. The event log was generated from a combination of fire department dispatch time data and fire scene data. This log provided markers representing physiologically significant time periods in the subject data stream. A list of fire-run markers included alarm, arrival on scene, fire attack, ventilation, search & rescue operations, overhaul, rehabilitation operations, scene departure, and return to station.

Qualitative Biomechanical Analysis

Using video data obtained from thermal imaging and visible light cameras, aspects of physical motion (typical movement patterns), were observed and examined for their physiological relevance. In conjunction with the LifeShirt® accelerometer data, this analysis provided needed insight into subject movement and posture during interior and exterior work periods. Video was analyzed during all three periods of suppression work and overhaul.

Data Analysis

ANOVA and Measures of Association

Breakdowns included average physiological responses to fire run events (alarm, fire suppression operations, rehab, overhaul, search & rescue operations, etc.). These data were also broken down further into responses based upon firefighter age, service experience gender, physical fitness level, and presence vs. absence of entrapped victims. Analysis of Variance (ANOVA) techniques were utilized to detect differences between the groups outlined in descriptive analyses. On and off duty STAI and Cortisol data were compared in similar fashion. Bivariate correlations (Pearson r) were examined among all physiological and fire-scene data to determine significant relationships.

To ensure subject number (N) is large enough to provide sufficient statistical power, a power analysis was performed a priori. A power analysis requires establishment of a desired statistical power level (in our case 0.80), a desired level of statistical significance (alpha level, in this case alpha ≤ 0.05), and an estimate of the size of an examined factor's effect on the dependent variable. Although little or no data exists on the physiological responses of firefighters to fire ground activity, our recent work with training firefighters (MFRI, 2006) provided sufficient data to estimate effect size for the majority of physiological variables to be examined. Based upon these estimates of effect size and our desired power level of 0.80, an ANOVA procedure performed at alpha ≤ 0.05 would require a minimum N of 50 individuals.

Data Modeling: Principle Components Analysis and Multiple Regression

A Principle Components Analysis (PCA) using physiological, fire scene, environmental and firefighter descriptive data was executed. This analysis illustrated relationships among firefighter responses and variables suspected of having significant physiological impact. Variables extracted by the PCA procedure were then subjected to multiple-regression in order to determine their relative importance in determining fire scene physiological responses. Using beta weights derived from regression, the relative impact of fire scene and firefighter descriptive data on various physiological responses will be determined.

This principle component analysis (PCA) procedure typically requires many measures (or cases) of independent and dependent variables. Tabachnick & Fidell (1996) suggest that PCA procedures include a minimum of 300 cases. Comrey & Lee (1992) rank case requirements on the following scale: 50 cases (very poor), 100 cases (poor), 200 cases (fair), 300 cases (good), and 500 cases (very good). This study monitored an average of 6.2 firefighters on 88 working structural fire incidents.

Indianapolis Fire Department Fire Equipment

To some extent, firefighter physiology will be affected by the tools of their trade. This includes how an individual apparatus is equipped. The two stations involved in the study possessed engine and ladder companies. A two-man rescue squad and a single-man tactical support vehicle were assigned to one of the participating stations.

Engines staffed by monitored firefighters included a 2007 Ferrara and a 2002 American LaFrance. Ladder companies staffed a 2002 American LaFrance 85ft tower and a 2007 Ferrara 100ft tower. The rescue squad is a 2004 F450 equipped for both ALS and BLS services.

Indianapolis Fire Department Fire Scene Duty Assignments

IFD standard operation procedures (SOP) dictate fire scene duty assignments are based upon the order of apparatus arrival. The first arriving engine company secures a primary water source and is responsible for primary fire attack. The first arriving ladder company consists of an inside team and an outside team. The inside team is responsible for primary search operations while the outside team is responsible for exterior ventilation operations. A second arriving engine company secures a secondary water source and is responsible for back-up attack operations. The second ladder company again is divided into inside and outside teams. The outside team assists the first ladder with ventilation operations. The inside team assists inside with fire attack operations. IFD's two-man rescue squads generally assist with search operations unless there is an immediate need for EMS operations on scene.

Study Results

STUDY RESULTS

STATION SELECTION

Stations were selected for study participation based upon multiple factors. However, the fundamental factor for selection was a station's volume of fire work. Table 1.1 illustrates recent run histories of the two stations selected for participation. Two fire stations were selected from IFD's available 35. These two stations chosen were located 1.5 miles apart and historically run together on many fires. The stations chosen are two of the busiest in the department and regularly the busiest in terms of working incidents (structural fires). The combination of these two stations provided a potential subject pool of 69 firefighters for recruitment. The primary coverage areas of these two stations (area where an engine and ladder company is first due at a fire scene) contained similar architectural styles. Lastly, Station B is a 4-apparatus station with a building large enough to accommodate the embedded scientists over the study period.

The embedded science team accompanied Stations A, B or both on 796 fire runs during the study period. Of those fire runs, 121 were declared working incidents by IFD. During 32 of those working incidents, studied firefighters were designated as RIT teams or were otherwise not involved in suppression operations. These incidents were eliminated from analyses leaving 88 working structural fires during which, studied firefighters were directly involved in suppression operations.

Table 1.1: 2006 Station Run History

	Fire Runs	EMS Runs	Total Runs
Engine A	1149	2013	3162
Ladder A	1023	326	1349
Engine B	1129	497	1626
Ladder B	1017	211	1228
Squad B	1096	2039	3135
TSU B	348	8	356

*Statistics Courtesy of Indianapolis Fire Department

SUBJECT DESCRIPTIVE DATA

Fifty-six (56) firefighters from Stations A and B volunteered for the study, representing a recruitment rate of 81%. Tables 2.1 through 2.3 provide mean physical characteristics of participating firefighters as well as measures of health related components of physical fitness. Additionally, tables provide comparative information from age and gender matched general US populations. Table 1.2 provides descriptions of the total subject pool while tables 1.2 and 1.4 break these data into gender specific descriptions. These gender-based data are provided only for descriptive purposes. For the purposes of examining firefighter responses, all subjects will be pooled. Table 2.4 outlines measures of association among demographic and fitness variables. Of particular significance is the lack of significant relationship between firefighter age and cardiovascular fitness (Vo_{2MAX})

Table 2.1: Physical Description and Fitness Data (ALL SUBJECTS)

	N	Minimum	Maximum	Mean ± STD
Age (yrs)	56	26	61	43.1 ± 7.95
Yrs of Service	56	3	34	16.8 ± 8.26
Height (in)	56	64	76	70.9 ± 2.17
Weight (lb)	56	132.31	321.7	200.8 ± 34.14
Systolic BP (mmHg)	56	104	160	127.9 ± 11.15
Diastolic BP (mmHg)	56	58	130	82.5 ± 10.1
Body Mass Index	56	22.2	43.7	28.1 ± 4.00

*Firefighter was not able to complete this portion of the test due to temporary physical limitation

Table 2.2: Physical Description and Fitness Data (MALES)

	N	Minimum	Maximum	Mean ± STD	US Population
Age (yrs)	52	26	61	43.1 ± 7.98	
Yrs of Service	52	3	34	17.0 ± 8.40	
Height (in)	52	66	76	71.2 ± 1.80	69.4 ± 0.1 [1]
Weight (lb)	52	154.4	321.7	204.2 ± 32.28	191.0 ± 1.0 [1]
Systolic BP (mmHg)	52	110	160	128.9 ± 10.83	
Diastolic BP (mmHg)	52	68	130	83.4 ± 9.70	
Body Mass Index	52	22	44	28.0 ± 3.96	27.9 ± 0.11
Hand Grip R	52	32	69	54.0 ± 8.16	35 - 62 [3]
Hand Grip L	52	32	68	53.0 ± 7.35	
Pushups	50	3	67	32.0 ± 15.24	10 - 30 [3]
Curlups	50	18	80	49.0 ± 3.20	15 - 60 [3]
Vo_{2MAX} (ml/kg/min)	51	34	65	47.0 ± 6.24	33.0 - 55.9 [2]

[1] Population statistics reflect values (Mean ± SEM) for the adult male US population (20 -70 years of age) National Center for Health Statistics 2004
[2] Wilmore, J.H. & Costill, D.L. 2005
[3] Canadian Physical Activity: Fitness & Lifestyle Approach

Table 2.3: Physical Description and Fitness Data (FEMALES)

	N	Minimum	Maximum	Mean ± STD	US Population
Age (yrs)	4	31	52	42.8 ± 8.69	
Yrs of Service	4	7	21	13.5 ± 5.80	
Height (in)	4	64	69	66.8 ± 2.63	64.0 ± 0.1 [1]
Weight (lb)	4	132.3	199.6	157.2 ± 30.31	164.3 ± 1.0 [1]
Systolic BP (mmHg)	4	104	122	115.5 ± 7.90	
Diastolic BP (mmHg)	4	58	84	71.5 ± 10.63	
Body Mass Index	4	22.8	29.5	24.7 ± 3.23	28.2 ± 0.2 [1]
Hand Grip R (kg)	4	28	37	33.0 ± 3.74	25 - 36 [3]
Hand Grip L (kg)	4	25.5	36	32.8 ± 4.91	
Pushups (1 min)	4	22	44	33.3 ± 10.44	5 - 30 [3]
Curlups (1 min)	4	44	63	52.3 ± 7.93	10 - 50 [3]
Vo_{2MAX} (ml/kg/min)	4	34.7	45.9	38.8 ± 4.91	23.6 - 41.0 [2]

[1] Population statistics reflect values (Mean ± SEM) for the adult male US population (20 -70 years of age) National Center for Health Statistics 2004
[2] Wilmore, J.H. & Costill, D.L. 2005
[3] Canadian Physical Activity: Fitness & Lifestyle Approach

Studied male firefighters were similar in stature, body weight, and body composition compared to their general population counterparts. Studied female firefighters were similar in stature while somewhat heavier and possessing a higher body mass index compared to their general population counterparts. Similar comparisons to the general populations were observed in firefighters studied in the MFRI study (MFRI, 2006).

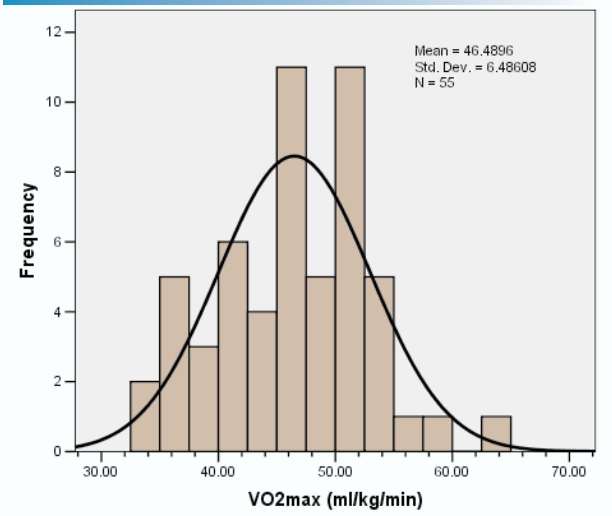
Cardiovascular fitness of male firefighters was toward the higher end of the normal range for the general male population. In addition, male firefighters possessed a level of general muscular strength (as indicated by their push up and hand grip scores), as well as general muscular endurance (as indicated by their curl up score). By comparison, Female firefighters scored at or above their general population counterparts in every fitness category measured. Again, this trend is similar to that reported in the MFRI study (MFRI 2006) where female firefighters are generally stronger and more fit than their general population counterparts. Heart rate responses to the Queens College Step test enabled a field estimate of cardiovascular fitness (Vo_{2MAX}). Across all studied firefighters (male & female), cardiovascular fitness was normally distributed and tightly centered near a mean value (Graph 2.1). This mean was considerably higher than the general population.

Table 2.4: Correlations Among Fitness-Related Variables

		Age	Yrs of	BMI	Hand Gr	Pushups	Curlups	Sys BP	Dia BP	VO2max
Age	Correlation	1	0.891	.016	-0.131	-0.471	-.064	0.127	0.161	-0.257
	Sig. (2-tailed).		0.000	0.932	0.335	0.000	0.646	0.352	0.235	0.058
Yrs	Correlation	0.891	1	0.110	-0.054	-0.505	-0.033	0.303	0.194	-0.203
	Sig. (2-tailed)	0.000		0.417	0.689	0.000	0.814	0.000	0.153	0.137
BMI	Correlation	0.012	0.110	1	0.420	-0.215	-0.097	0.230	0.162	-0.209
	Sig. (2-tailed)	0.932	0.417		0.001	0.119	0.487	0.000	0.233	0.126
Hand Gr	Correlation	-0.131	-0.055	0.420	1	0.172	-0.067	0.156	0.252	0.132
	Sig. (2-tailed)	0.335	0.689	0.001		0.214	0.630	0.250		0.337
Pushups	Correlation	-0.471	-0.506	-0.215	0.172	1	0.274	-0.384	-0.268	0.273
	Sig. (2-tailed)	0.000	0.000	0.119	0.214		0.045	0.004	0.050	0.046
Curlups	Correlation	-0.064	-0.033	-0.097	-0.630	0.274	1	0.057	-0.125	0.101
	Sig. (2-tailed)	0.646	0.814	0.487	0.63	0.045		0.680	0.369	0.466
Sys BP	Correlation	0.127	0.303	0.230	0.156	-0.384	0.057	1	0.704	0.009
	Sig. (2-tailed)	0.352	0.023	0.088	0.250	0.004	0.680		0.000	0.944
Dia BP	Correlation	0.161	0.194	0.162	0.252	-0.268	-0.125	0.704	1	0.004
	Sig. (2-tailed)	0.235	0.153	0.233	0.006	0.050	0.369	0.000		0.806
VO2max	Correlation	-0.257	-0.203	-0.209	0.132	0.272	0.101	0.000	0.003	1
	Sig. (2-tailed)	0.058	0.137	0.126	0.337	0.004	0.466	0.944	0.806	

** Significant at the p = 0.001 level
* Significant at the p = 0.005 level

Graph 2.1: Cardiovascular Fitness Distribution



In general, the firefighters studied here were larger, stronger and possessed better cardiovascular fitness than the average person on the street. This fact will become extremely important when responses to fire scene work are considered. Because of their high fitness level, this group of firefighters can be considered a model or ideal group when examining their responses to fire scene work. A specific job or workload will result in lower cardiovascular and respiratory responses in this group compared to a lesser fit group of individuals. Unfortunately, previous studies of firefighter physiological responses to fire ground work either have few subjects (18) or do not report physical characteristics of their subjects (21).

FIREFIGHTER DEMOGRAPHICS

Racial distribution among the studied firefighters reflects that of Marion County Indiana (US Census Bureau, 2006). The average firefighter studied was 43 years of age, married and had 16 years of experience in the fire service). Apparatus assignments were evenly distributed between Engine and Ladder companies providing equal opportunity to study engine and ladder company work. Firefighter service ranks reflect the standard distribution of personnel (NFPA 1710) with approximately half of the studied individuals on the back step and half engineers and company officers. Charts 2.1 and 2.2 provide demographic characterization of the subject pool with respect to race and marital status.

Chart 2.1: Subject Racial Distribution

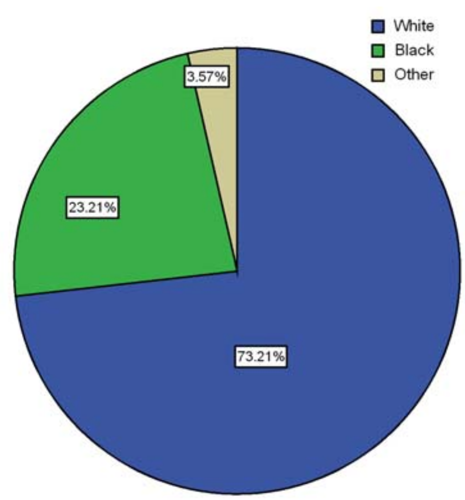


Chart 2.2: Subject Marital Status Distribution

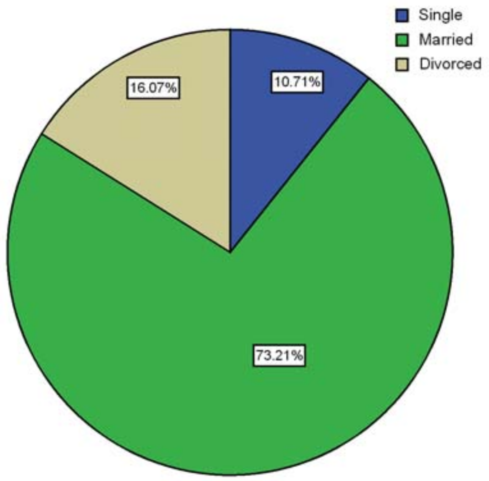
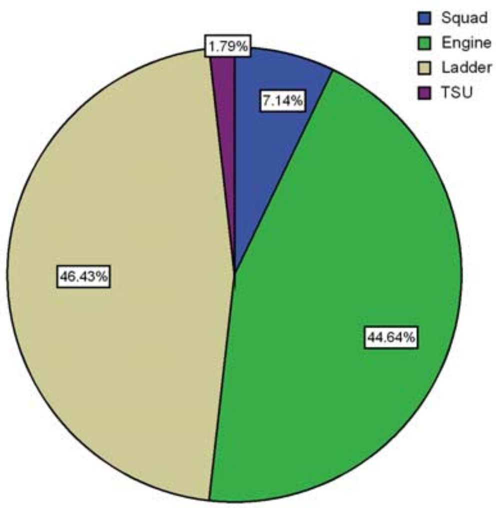
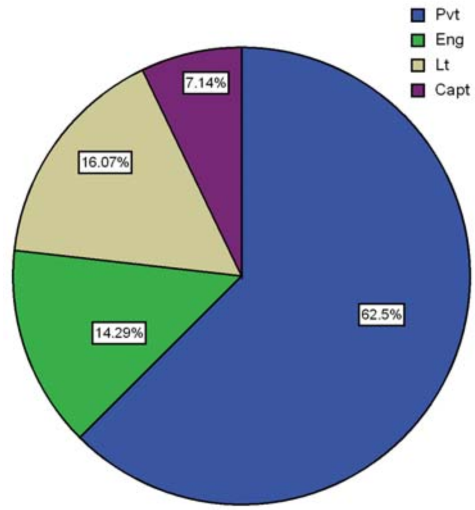


Chart 2.3: Subject Apparatus Assignment



Charts 2.3 and 2.4 represent distributions of the subject pool across fire apparatus assignments, ranks and duty shifts respectively

Chart 2.4: Subject Fire Service Rank



Dispatch & Arrival Information

Charts 2.5 through 2.7 illustrate descriptive information concerning Alarm and Dispatch information alerting subject firefighters to emergency runs. Considering the typical structure size in the primary study's primary response area, the distribution of Still vs. Box alarms appears appropriate. IFD standard operating procedures require dispatch to apartments as Box alarms. Other structures in the primary response area include large commercial buildings and schools. This is reflected in the overwhelming majority of dispatch to residences vs. apartments or other structures.

Chart 2.5: Alarm Type

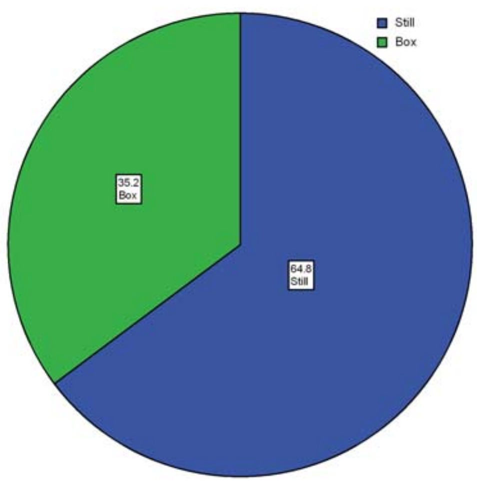
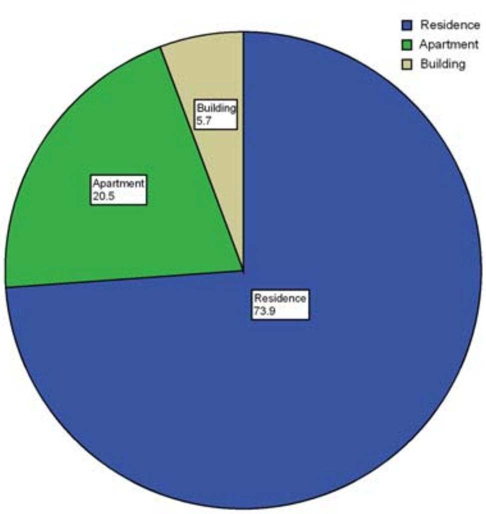
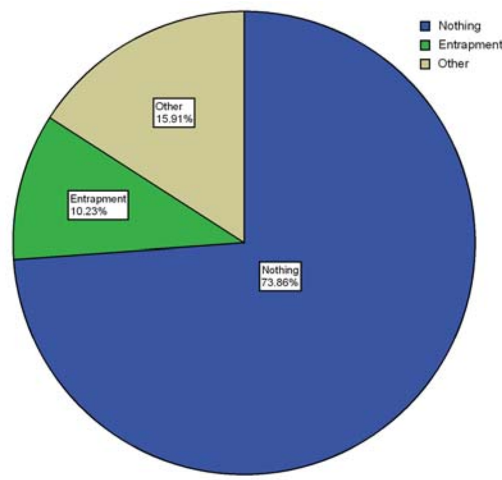


Chart 2.6: Dispatch Type



Information provided to responding companies by dispatchers (Chart 2.7) indicate the possibility of entrapped occupants or other situational factors occurred in approximately 25% of runs. The influence of this information on firefighter physiology will be discussed later

Chart 2.7: Dispatch Information



During the study period, scientists and monitored firefighters answered 723 fire runs. 118 of those runs were determined to be working structural fire incidents. During thirty (30) of the structural fire incidents, studied personnel were designated as a rapid intervention (RIT) team or were not otherwise involved in suppression operations. Those incidents were removed from the analysis. The 88 structural fire incidents entered in the analysis averaged 6.2 monitored firefighters per incident (range: 4-13).

Operational assignments for firefighters are established by the arrival order of their company. Table 2.5 outlines the frequency of arrival order for each ladder and engine company participating. IFD Standard operating procedures (SOPs) indicate only one Rescue Squad (Squad 10) and Tactical Service Unit (TSU10) is dispatched on single alarm incidents. Therefore, those apparatus were always 1st arrival.

Table 2.5: Summary of Company Arrival Order

Apparatus	Arriving 1st		Arriving 2nd		Arriving 3rd		Arriving 4th	
Engine B	22	41.5%	19	35.8%	10	18.9%	2	3.8%
Ladder B	29	52.7%	18	32.7%	7	12.7%	1	1.8%
Engine A	8	44.4%	9	50.0%			1	5.6%
Ladder A	6	30.0%	10	55.0%	3	14.9%	1	5.0%

On arrival at the fire scene, descriptive information about the burning structure was collected. Charts 2.8 and 2.9 show nominal data utilized to describe structures. These data reflect the distribution of architectures within the response area studied. The area is typified by wood framed residential structures with a lesser portion made up of apartments and other structure types

Chart 2.8: Building Type

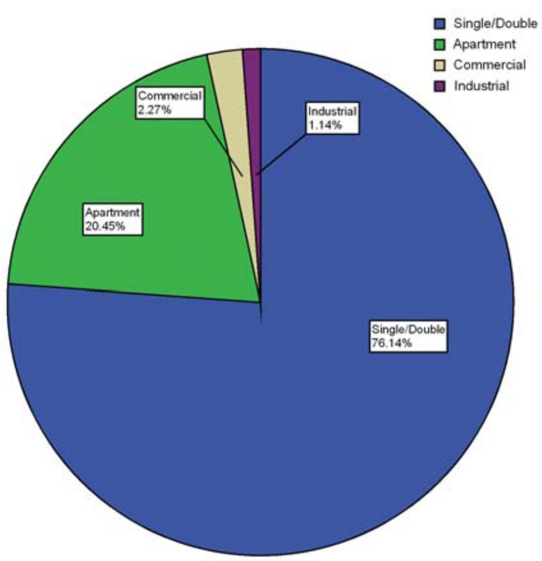


Chart 2.9: Construction Type

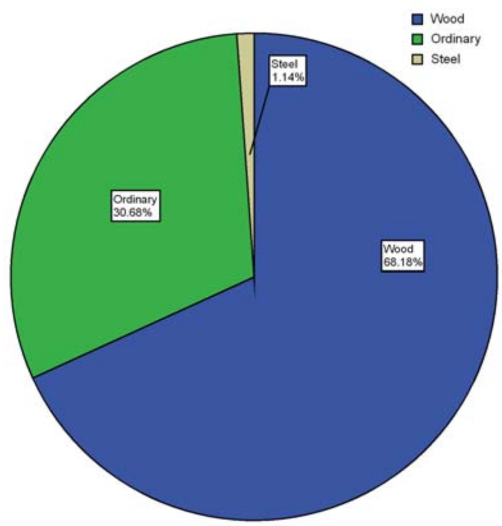


Table 2.6 outlines frequencies of fire scene size up data collected to establish the situation upon arrival of the first working company. First on scene companies typically find structures 0-25% involved with fire & heavy grey to black smoke showing. Fires are generally located on the first floor of the structure primarily due to the fact that the majority of the structures are single story residences

Table 2.6: Fire Scene Size-up Information

Descriptor		Frequency	Sig
Situation	Nothing Showing	3	3.4
	Smoke Showing	48	54.5
	Fire Showing	3	3.4
	Fire/Smoke Showing	34	38.6
Involvement	0-25%	38	43.2
	25-50%	24	27.3
	50-75%	18	20.5
	75-100%	8	9.1
Fire Location	Basement	15	17
	1st Floor	41	46.6
	2nd Floor	18	20.5
	2nd Floor & Exposures	3	3.4
	1st & 2nd Floors	4	4.5
	1st & 2nd Floors & Exposures	1	1.1
	3rd Floor	3	3.4
	Basement & 1st Floor	1	1.1
	Attic	2	2.3
Smoke Color	White	10	11.4
	Gray	43	48.9
	Brown	6	6.8
	Black	29	33
Smoke Volume	Light	25	28.4
	Moderate	22	25
	Heavy	41	46.6

Weather conditions on the fire ground were also monitored. Ambient air temperature and relative humidity were recorded. Where appropriate, wind chill or heat index was calculated for each scene. Table 2.7 outlines the mean weather parameters observed on scene. These weather data are typical for central Indiana during the winter and spring months. As such, they present little or no ambient heat stress for the firefighters. Thus, examination of the physiology of firefighting here reflects a more accurate picture of the cardiovascular and respiratory stress associated with the work of fighting fire than if the study was conducted during the summer months. The effects of ambient heat stress will be addressed in subsequent studies by collecting data in a more heat stressed geographic region of the country.

Table 2.7: Summary of Fire Scene Weather

	N	Min	Max	Mean	STD
Temperature (C)	88	-7.6	29	8.3	8.9
Humidity (%)	88	28.4	96	65.3	18.9
Wind Chill (C)	88	-14	28	5.5	9.7

Cardiovascular and Respiratory Responses to Alarm

In order to determine the extent of heart stress associated with being alerted by alarm, heart rate was examined over a 90 second period immediately following the alarm. Heart rate and relative heart rate (%HR_{MAX}) during the 90 second period were examined as well as the time to peak heart rate (HRP*t*). Table 3.1 describes the HR responses to the alarm across all alarm types.

In Table 3.2, the relationships between alarm heart rate response and subjects are characterized. These data indicate that heart rate responses are closely associated with firefighter experience (years of service) and fitness (Vo_{2MAX}). Relative heart rate response is also associated with fitness. Reporting on 35 firefighters responding to 189 alarms, Barnard & Duncan (21) reported similar

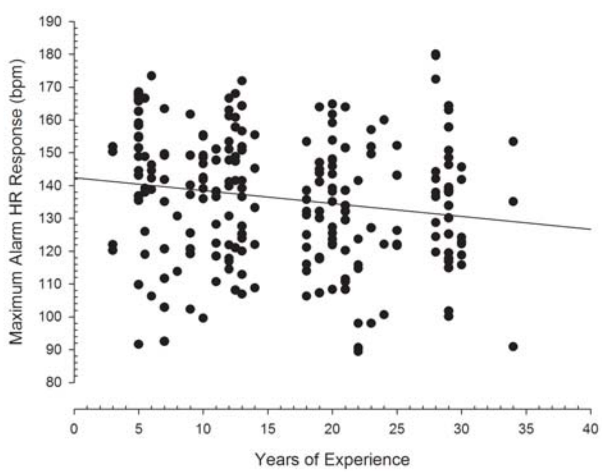
Table 3.1: Alarm Response Descriptives

	Min	Max	Mean	STD
Alarm HRmax	89.4	180.1	136.1	19.584
% HRmax	48.7	108.5	76.9	11.320
HRP*t*	0.270	2	1.2	0.4633

Table 3.2: Alarm Response Variable Correlations

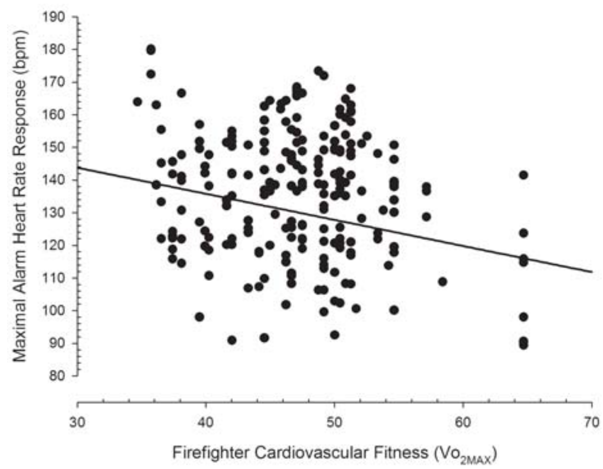
		Alarm HRmax	% HRmax	HRPt	Age	Yrs service	VO2max
Alarm HRmax	Correlation	1	0.950	-0.116	-0.099	-0.169	-0.219
	Sig. (2-tailed)		0.000	0.084	0.138	0.011	1.10
% HRmax	Correlation	0.950	1	-0.073	0.214	0.108	-0.267
	Sig. (2-tailed)	0.000		0.274	0.001	0.106	0.000
HRPt	Correlation	-0.116	0.073	1	0.122	0.113	-0.036
	Sig. (2-tailed)	0.081	0.274		0.066	0.887	0.600
age	Correlation	0.099	0.214	0.122	1	0.879	-0.129
	Sig. (2-tailed)	0.138	0.001	0.066		0.000	0.042
yrs service	Correlation	-0.169	0.108	0.113	0.879	1	-0.009
	Sig. (2-tailed)	0.001	0.106	0.887	0.000		0.887
VO2max	Correlation	-0.21	-0.267	-0.036	-0.129	-0.009	1
	Sig. (2-tailed)	0.001	0.000	0.600	0.042	0.887	

Graph 3.1: Effect of Firefighter experience on maximal alarm Heart Rate response.



HRmax = (Years of Service *0.4075) + 136.7064
R = 0.16875041, SEE = 0.1523

Graph 3.2: Firefighter fitness effects on maximal alarm heart rate response

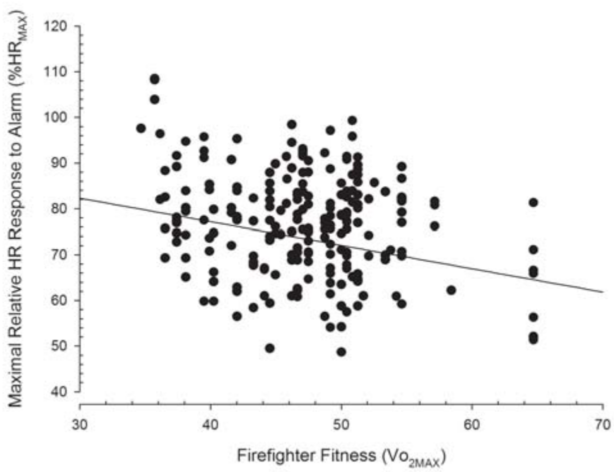


HRmax = (Fitness * -0.7992) + 167.7577
R = 0.26, SEE= 0.1505

The measures of association in Table 3.2 suggest a cause and effect relationship between firefighter experience and fitness with firefighter heart arte response to alarm. Graph 3.1 indicates that as firefighters gain work experience, their heart rate response to alarm lessens.

Graph 3.2 demonstrates the relationship between firefighter fitness and maximal alarm heart rate response. This data indicates that maximal heart rate response to the alarm declines as firefighter fitness improves.

Graph 3.3: Effects of Firefighter Fitness on relative maximal heart rate alarm response



$\%HRmax = (Vo_{2MAX} * -0.5105) + 97.59$
$R = 0.28$, $SEE = 0.1514$

In addition, Graph 3.3 indicates that the relative heart rate response to alarm declines with improved firefighter cardiovascular fitness.

These findings differ from those reported earlier by Kuorinka & Korhonen (38). These authors found an positive relationship between firefighter fitness and heart rate response to alarm. In other words, the more fit firefighters in their study had greater heart rate increases in response to alarm. However this observation was based solely upon the observations of nine firefighters.

Responses to Alarm Types

To determine the effect of different alarm types on heart stress, heart rate responses were examined between Still and Box alarms. Table 3.3 illustrates heart rate responses induced by different alarm types. Table 3.4 contains the ANOVA F-table indicating no heart rate differences were detected between Still and Box alarms.

Table 3.1: Heart rate Responses to Alarm types

		Mean	STD	Min	Max
HRmax	STILL	135.0	18.89	89.4	179.6
	BOX	138.7	20.0	90.3	180.1
% HRmax	STILL	76.7	10.9	49.5	108.2
	BOX	77.9	11.5	51.9	108.5
HRP*t*	STILL	1.189	0.455	0.350	2
	BOX	1.174	0.472	0.280	1.98

Table 3.4: Alarm Type Differences F-Table

		SS	df	MS	F	sig
HRmax	B/n Grps	721.9	1	721.9	1.93	0.170
	W/n Grps	81.86	219	373.8		
	Total	82.58	220			
% HRmax	B/n Grps	74.59	1	74.59	0.597	0.440
	W/n Grps	27338.4	219	124.8		
	Total	27413.0	220			
HRP*t*	B/n Grps	0.012	1	0.002	0.056	0.812
	W/n Grps	46.8	219	0.214		
	Total	46.8	220			

Cardiovascular and Respiratory Responses to Fire Ground Ingress

Fire ground ingress was defined as the time period between exiting the station and arrival of an apparatus at the fire scene. Table 4.illustrates the effects of dispatch information on firefighter physiology during ingress. Table 4.2 shows the F-test of statistical significance between different types of dispatch information effecting firefighter physiology. With dispatch or during Ingress, firefighters may receive information about the fire scene. Some of this information has a measureable effect on firefighter physiology. Information provided to participating firefighters, was divided into three categories. Nothing refers to a situation where no additional information was provided during ingress. Entrapment refers to either the possibility or the confirmation of civilian entrapment at the fire scene. Other information refers to any information other than entrapment provided during ingress. This information commonly referenced security of the scene, road conditions, or possible threats to public safety personnel.

Table 4.1: Effect of Dispatch Information on Ingress Physiology

		N	Mean	Standard Deviation	Minimum	Maximum
VT	Nothing	180	1189.2	451.7	617.8	3099.3
	Entrapment	32	1299.9	303.4	738.6	1941.1
	Other	37	1159.4	341.3	711	1964.3
VE	Nothing	180	33.1	20.9	7.8	121.4
	Entrapment	32	37.9	12.9	16.9	63.5
	Other	37	33.7	17.4	12.7	79.2
Breaths/min	Nothing	180	36	7.7	14.5	57.2
	Entrapment	32	36	5.1	27.2	44
	Other	37	37.5	7	24	50
Heart Rate	Nothing	161	99.4	19.2	57.7	145.2
	Entrapment	31	112.6	14.4	85.8	136
	Other	34	100.4	19.6	69.3	131.7
% HR max	Nothing	161	56.4	10.7	32	85
	Entrapment	31	63.4	8.4	47	77
	Other	34	56.2	11.1	36	75

Table 4.2: Effect of Dispatch Information on Ingress Physiology

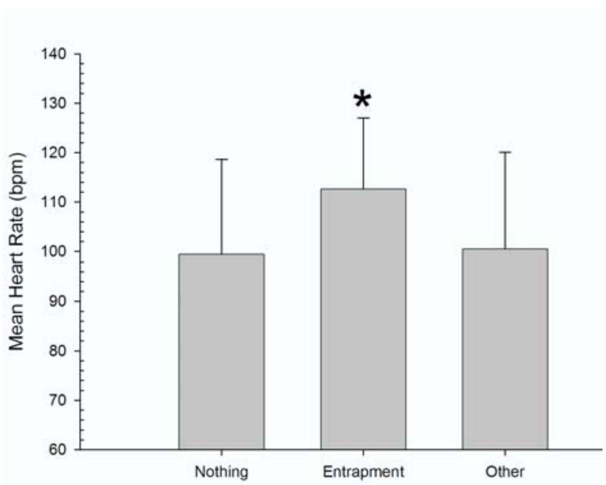
		Sums of Squares	df	Mean Square	F	Sig.
VeVol	Between Groups	4009808	2	200490.4	1.130	0.324
	Within Groups	43576365.4	246	177139.7		
Ventilation	Between Groups	612.4	2	306.2	0.800	0.450
	Within Groups	94029.5	246	382.2		
Breaths/min	Between Groups	73.9	2	37	0.690	0.502
	Within Groups	13155.5	246	53.5		
Heart Rate	Between Groups	4527.4	2	2263.7	6.5	0.002
	Within Groups	78081.6	223	350.1		
% HR max	Between Groups	1324.4	2	662.2	6	0.003
	Within Groups	24638.6	223	110.5		

Table 4.3: Tukey Post Hoc Comparison of Physiological Differences during Ingress

Dependent Variable	(I) Dispatch Info	(J) Dispatch Info	Mean Diff (I-J)	Stand Error	Sig
Heart Rate	Nothing	Entrapment	-13.1	3.670	0.001
		Other	-1.0	3.532	0.956
	Entrapment	Nothing	13.1	3.670	0.001
		Other	12.1	4.647	0.027
	Other	Nothing	1.0	3.532	0.955
		Entrapment	-12.1	4.647	0.026
% HR max	Nothing	Entrapment	-7.0	2.062	0.003
		Other	0.2	1.984	0.993
	Entrapment	Nothing	7.0	2.062	0.002
		Other	7.2	2.610	0.017
	Other	Nothing	-0.2	1.984	0.993
		Entrapment	-7.2	2.610	0.017

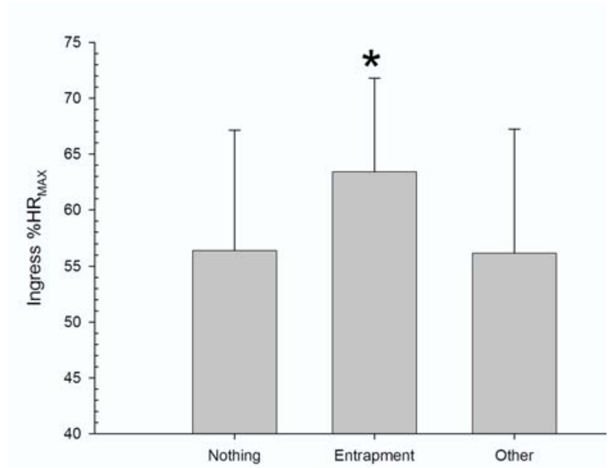
After significant differences were established, heart rate and relative heart rate differences were graphed to illustrate the observed differences. Graph 4.1 reflects differing Ingress heart rate responses observed as a function of dispatch information. These data indicate when entrapment is suspected, firefighters experience significant increases in cardiovascular stress prior to arrival at the fire scene. During Ingress firefighters are generally seated in an apparatus and little or no physical work is done. Therefore, the stress induced is an emotionally-driven sympathetic nervous system response (adrenaline outflow) to the information about entrapment.

Graph 4.1: Effect of Dispatch Information on Ingress Heart Rate



(*) Entrapment > Nothing, Entrapment > Other ($p< 0.05$)

Graph 4.1: Effect of Dispatch Information on Ingress %Heart Rate Max



(*) Entrapment > Nothing, Entrapment > Other ($p< 0.05$)

Tables 4.4 and 4.5 indicate that a significant relationship exists between the cardiovascular fitness of a firefighter (as indicated by Vo_{2MAX}) and the individual's heart rate during Ingress to the fire scene. The relationship is illustrated by graph 4.3.

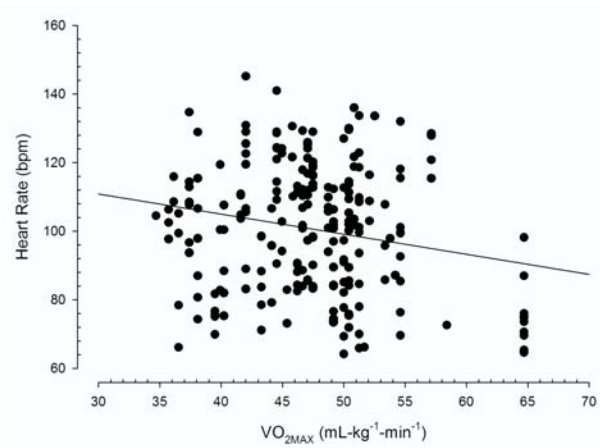
Table 4.4: Regression Vo_{2MAX} on HR

ANOVA						
		SS	df	MS	F	sig
Model	Reg	3253.9	1	3253.9	9.2	0.003
	Resid	78546.4	222	353.8		
	Total	81800.4	223			

Table 4.5: Regression Coefficients Vo_{2MAX} vs HR

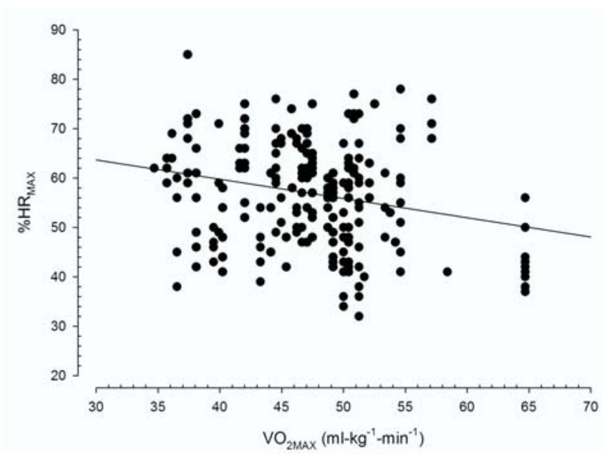
Coefficients						
		Unstand Coef		Stand Coefs		
		B	Std	Beta	t	sig
Model	(Cons	129.5	9.4		13.7	0.000
	VO2m	-0.598	0.197	-0.199	-	0.003

Graph 4.4: Vo_{2MAX} regressed on Ingress Heart Rate



HR = (-0.598 * Vo_{2MAX}) + 129.5 R = 0.199, R^2 = 0.040

Graph 4.5: Vo_{2MAX} regressed on Ingress $\%HR_{MAX}$



HR = (-0.399 * Vo_{2MAX}) + 76..04 R= 0.237, R^2 = 0.056

Table 4.6 indicates that a relationship does not exist between firefighter fitness (as indicated by Vo_{2MAX}) and firefighter minute ventilation (V_E) during Ingress to a fire scene.

Table 4.6: Regression Vo_{2MAX} on Ingress V_E

ANOVA						
		SS	df	MS	F	sig
Model	Regr	55.7	1	55.7	0.147	0.702
	Resid	92830.2	245	378.9		
	Total	92885.9	246			

Cardiovascular and Respiratory Responses Suppression Operations

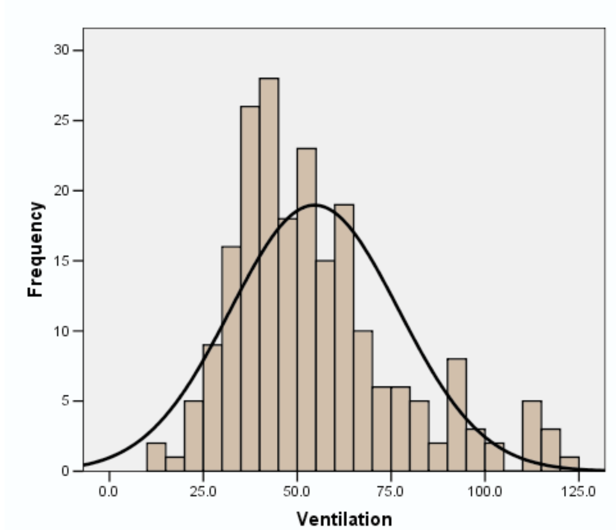
Physiological characteristics and duration of individual work phases of suppression operations were examined. Primary cardiovascular and respiratory physiological responses to each phase of suppression operations are outlined in Tables 5.1 through 5.4. Data presented in Table 5.1 represents overall responses to the fire scene across all work phases. The heart rate data illustrated here for overall suppression operations is similar to that described earlier (Sothmann, 1992 & Barnard, 1975).

Table 5.1: Overall Suppression Ops Physiology Descriptives

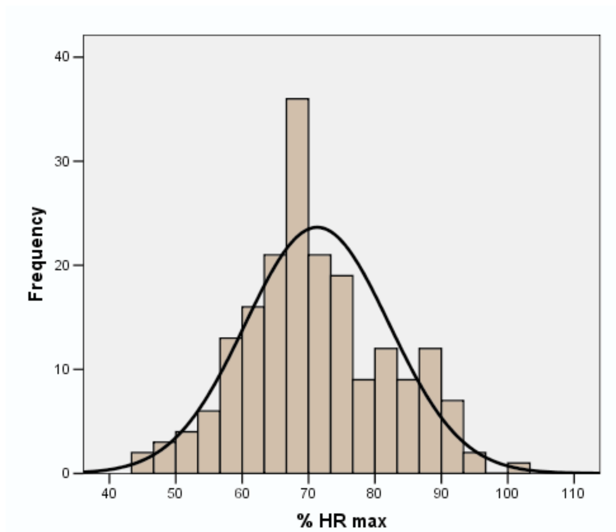
	Min	Max	Mean	STD
Duration	1.68	120.4	16.2	21.1
VeVol	699.8	3538.5	1569.0	523.0
VE	12.5	124.2	54.6	22.4
Brs/min	19.8	60.9	40.6	6.1
AccM	1.9	14.1	7.9	1.8
HR	81.9	170	126.2	19.8
%HR max	45	101	71.3	10.8

Graph 5.1 illustrates the frequency of ventilatory responses to fire suppression operations. Graph 5.2 illustrates the frequency with which levels of relative heart stress occurred during suppression operations. These data indicate that the typical firefighter response to fire ground operations is in excess of 70% of maximal heart rate and that on any given fire scene, nearly 70% of firefighters are working between 60% to 80% of their maximal heart rate. Similarly, the average firefighter is breathing at a minute ventilation of 50 L/min and 70% of firefighters are consuming between 28 and 78 L/min of SCBA air. Consuming air at these rates gave studied firefighters an average of approximately 28 minutes of air.

Graph 5.1: Frequency of Suppression Ops Minute Ventilation Responses



Graph 5.2: Frequency of Suppression Ops Relative Heart Rate Responses



Physiological responses were further explored by examining responses to individual Suppression operational work phases. Tables 5.2 contains data from individual suppression work phases, Fire Attack, Ventilation and Search respectively.

Table 5.6 is an F-statistic table showing significance of differences observed between suppression work phases. No differences were detected between suppression operations work phases with respect to duration or any measures of respiratory physiology. However, differences were detected between work phases with respect to raw heart rate and relative heart rate

Table 5.2: Suppression Operations Work Phase Physiological Responses

	Phase	Mean	STD	Min	Max
Duration	Attack	18.9	24.36	3.6	120.4
	Ventilation	16.9	25.47	1.8	120
	Search	12.2	9.51	1.7	45.3
VeVol	Attack	1596.1	582.74	829.4	3538.5
	Ventilation	1434.8	455.65	699.8	2619.3
	Search	1646.6	484.68	768.0	3155.8
Ventilation	Attack	56.2	23.91	24.2	119
	Ventilation	49.1	18.61	12.5	111.9
	Search	57.2	22.90	12.9	124.2
Breaths/min	Attack	41.4	5.65	30.8	60.9
	Ventilation	40.4	6.81	26.5	57.6
	Search	39.7	6.04	19.8	55.1
AccM	Attack	8.0	1.93	4.9	14.1
	Ventilation	7.4	1.62	2.3	10.7
	Search	8.0	1.68	1.9	12
Heart Rate	Attack	125.4	16.6	84.9	163.6
	Ventilation	117.1	20.20	81.9	156.3
	Search	134.6	19.61	84.4	170.0
%HRmax	Attack	71.4	9.09	49.0	92.0
	Ventilation	66.7	11.59	45.0	96.0
	Search	75.0	10.78	46.0	101.0

Table 5.3: Suppression Op work phase differences in Firefighter Physiological Response

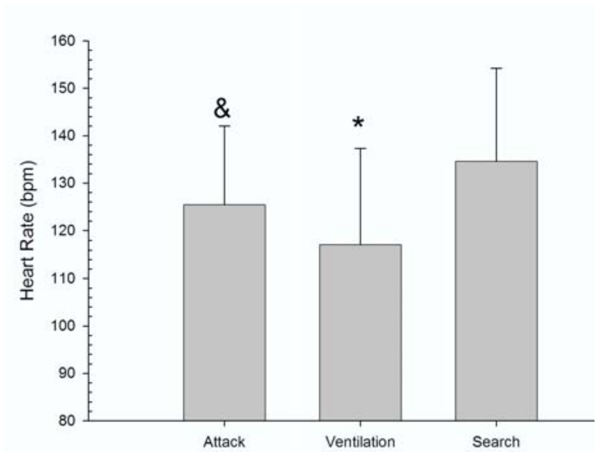
ANOVA						
		Sum of Squares	df	Mean Square	F	sig
Duration	Between Groups	1781.2	2	890.6	2.01	0.136
	Within Groups	94341.4	213	442.92		
	Total	96122.6	215			
VeVol	Between Groups	1533758.4	2	766879.21	2.85	0.060
	Within Groups	56463808.3	210	268875.28		
	Total	57997566.7	212			
Ventilation	Between Groups	2438.5	2	1219.24	2.46	.088
	Within Groups	103897.1	210	494.75		
	Total	106335.6	212			
Breaths/min	Between Groups	107.5	2	53.73	1.44	0.240
	Within Groups	7850.7	210	37.38		
	Total	7958.2	212			
AccM	Between Groups	16.7	2	8.36	2.66	0.072
	Within Groups	665.2	212	3.14		
	Total	681.9	214			
Heart Rate	Between Groups	9065.8	2	4532.92	12.98	0.000
	Within Groups	66333.1	190	349.12		
	Total	75398.9	192			
% HR max	Between Groups	2012.8	2	1006.40	9.29	0.000
	Within Groups	20589.8	190	108.37		
	Total	22602.6	192			

With differences detected among the physiological variables between work phases, a Tukey post-hoc analysis was performed to determine where differences exist between work phases. Table 5.7 outlines the results of the post-hoc analysis and Graphs 5.1 and 5.2 illustrate the detected differences in Heart rate and relative heart rate respectively.

Table 5.7: Post-Hoc Analysis of work phase physiological differences

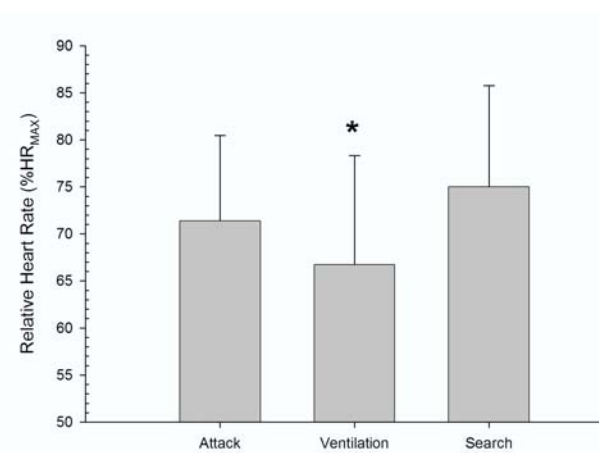
	(I) Phase	(J) Phase	Mean Difference (I-J)	Standard Error	Sig.
Heart Rate	Attack	Ventilation	8.3	3.34	3.70
		Search	-9.2	3.18	0.001
	Ventilation	Attack	-8.3	3.34	0.004
		Search	-17.5	3.44	0.000
	Search	Attack	9.2	3.18	0.012
		Ventilation	17.5	3.44	0.000
% HR max	Attack	Ventilation	4.6	1.86	0.036
		Search	-3.6	1.77	0.104
	Ventilation	Attack	-4.6	1.86	0.036
		Search	-8.2	1.92	0.000
	Search	Attack	3.6	1.77	0.104
		Ventilation	8.2	1.92	0.000

Graph 5.3: Suppression Ops differences in Heart Rate response



(*) Ventilation < Search, Ventilation < Attack
(&) Attack < Search

Graph 5.4: Suppression Ops differences in % Heart Rate Max response



(*) Ventilation < Search, Ventilation < Attack

Graphs 5.3 and 5.4 indicate search operations induce the highest heart rates during suppression operations. This high heart rate is most likely due to the physical stress of a fast-paced operation combined with the influence of the emotional stress of working in a dangerous environment. In the event search operations turn into a rescue operation, heart rate sky rockets. The highest heart rates observed during the study were in individuals involved in rescue of civilian victims. Some heart rates observed in rescue operations were in excess of 100% of predicted heart rate maximums and sustained for 20 to 40 minutes. Heart rates of this magnitude are extreme and may be responsible for triggering catastrophic cardiovascular events seen in firefighters possessing underlying heart disease.

Unfortunately, it appears nothing about the firefighter (Age, Experience, or Fitness level) is able to blunt or mitigate these responses. Data presented in Table 5.8indicate no relationship was detected between relative heart rate (%HRmax) and firefighter age, experience, or fitness level during suppression operations. On the surface, it may appear counter-intuitive to consider dissociation between fitness level and heart stress. However, it is important to note fitness here is an estimate of aerobic fitness. In fact, little if any of the work done during suppression operations is aerobic in nature. Therefore, a lack of association here between fitness level and cardiac stress during suppression ops is not surprising.

To discuss the work-induced stress placed upon the heart, blood pressure must also be considered. The product of heart rate and systolic blood pressure, known as the rate pressure product, is an indicator of work of the heart and the rate at which blood flow must be delivered to cardiac tissue. . Work that involves crawling and crouching body positions have the potential to drastically increase blood pressure as well as heart rate. This creates a hazardous situation for persons with underlying heart disease.

Physiology of Overhaul Operations

Overhaul operations were separated here from suppression operations. Overhaul operations are executed under different psychological and physiological stress environments compared to suppression operations. None the less, overhaul work represented a substantial physiological load to the firefighter. Table 6.1 outlines the physiological responses observed during overhaul work.

Table 6.1: Overhaul Descriptive Physiological

	Min	Max	Mean	STD
VeVol	681.9	3131.1	1321.0	427.8
Ventilation	12	114.9	43.0	19.8
Breaths/min	26.4	60.4	39.5	6.4
AccM	1.3	9.5	6.3	1.7
Heart Rate	65.1	153.9	116.9	15.0
% HR max	37	86	66.0	8.8

Overhaul responses were compared to suppression operations to detect differences in physiological demand. Table 6.2 contains the ANOVA F-table outlining these comparisons. Differences were detected between physiological variables during Overhaul and those of suppression operations work phases. The Post-Hoc analysis (Tables 6.3a and 6.3b) identified differences between Overhaul and suppression operations work phases.

Table 6.2: GLM analysis of Overhaul and Suppression Operations Phase Differences

Tests of Between-Subjects Effects						
Source	**Dependent Variable**	**SS**	**df**	**MS**	**F**	**sig**
Corrected Model	VeVol	6413920.62	3	2137973.54	8.80	0.000
	Ventilation	13406.95	3	4468.98	9.41	0.000
	Breaths/min	257.32	3	85.77	2.25	0.083
	AccM	206.26	3	68.75	23.44	0.000
	Heart Rate	15673.34	3	5224.45	17.28	0.000
	% HR max	4159.23	3	1386.41	14.33	0.000
Intercept	VeVol	657724263.47	1	657724263.46	2706.57	0.000
	Ventilation	781879.07	1	781879.07	1647.08	0.000
	Breaths/min	473680.55	1	473680.55	12423.30	0.000
	AccM	15987.46	1	15987.46	5450.51	0.000
	Heart Rate	4383100.27	1	4383100.28	14494.40	0.000
	% HR max	1400203.39	1	1400203.39	14477.45	0.000
phase	VeVol	6413920.62	3	2137973.54	8.80	0.000
	Ventilation	13406.95	3	4468.98	9.41	0.000
	Breaths/min	257.3	3	85.8	2.25	0.083
	AccM	206.3	3	68.7	23.44	0.000
	Heart Rate	15673.3	3	5224.4	17.28	0.000
	% HR max	4159.2	3	1386.4	14.33	0.000
Error	VeVol	75819202.2	312	243010.3		
	Ventilation	148108.2	312	474.7		
	Breaths/min	11896.1	312	38.1		
	AccM	915.2	312	2.9		
	Heart Rate	94348.7	312	302.4		
Total	VeVol	778318767.1	316			
	Ventilation	976042.7	316			
	Breaths/min	529233.8	316			
	AccM	17755.8	316			
	Heart Rate	485	316			
Corrected Total	VeVol	82233122.8	315			
	Ventilation	161515.2	315			
	Breaths/min	12153.4	315			
	AccM	1121.4	315			
	Heart Rate	110022.0	315			
	% HR max	34334.7	315			

Table 6.3a: GLM Post Hoc analysis of Overhaul and Suppression Op Phase Differences

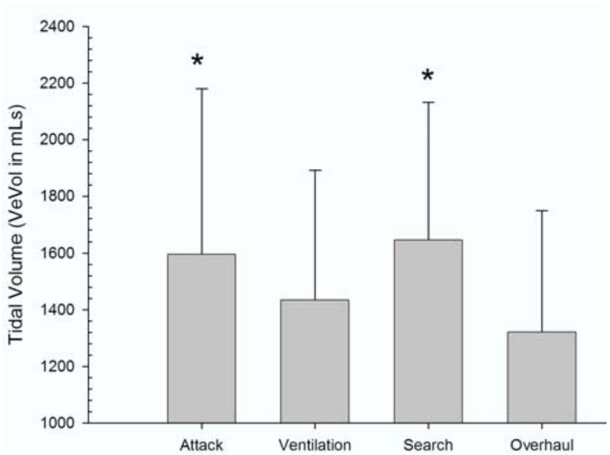
Dependent Variable	(I) Phase	(J) Phase	Mean Difference (I-J)	Std# Error	Sig#
VeVol	Attack	Ventilation	169.8	88.48	0.222
		Search	-68.7	84.07	0.846
		Overhaul	273.3	72.72	0.001
	Ventilation	Attack	-169.8	88.48	0.222
		Search	-238.5	90.77	0.044
		Overhaul	103.5	80.37	0.571
	Search	Attack	68.7	84.07	0.846
		Ventilation	238.5	90.77	0.044
		Overhaul	342.0	75.49	0.000
	Overhaul	Attack	-273.3	72.72	0.001
		Ventilation	-103.5	80.37	0.571
		Search	-342.0	75.49	0.000
Ventilation	Attack	Ventilation	7.6	3.91	0.212
		Search	-1.6	3.72	0.972
		Overhaul	13.4	3.21	0.000
	Ventilation	Attack	-7.6	3.91	0.212
		Search	-9.2	4.01	0.101
		Overhaul	5.8	3.55	0.354
	Search	Attack	1.6	3.71	0.972
		Ventilation	9.2	4.01	0.101
		Overhaul	15.1	3.34	0.000
	Overhaul	Attack	-13.4	3.21	0.000
		Ventilation	-5.8	3.55	0.354
		Search	-15.1	3.34	0.000
Breaths/min	Attack	Ventilation	1.3	1.11	0.632
		Search	1.8	1.05	0.297
		Overhaul	2.3	0.91	0.050
	Ventilation	Attack	-1.3	1.11	0.632
		Search	0.5	1.14	0.967
		Overhaul	1.0	1.01	0.754
	Ventilation	Attack	-7.6	3.91	0.212
		Search	-9.2	4.01	0.101
		Overhaul	5.8	3.55	0.354
	Search	Attack	1.6	3.71	0.972
		Ventilation	9.2	4.01	0.101
		Overhaul	15.1	3.34	0.000

Table 6.3b: GLM Post Hoc analysis of Overhaul and Suppression Op Phase Differences

Dependent Variable	(I) Phase	(J) Phase	Mean Difference (I-J)	Std# Error	Sig#
AccM	Attack	Ventilation	0.58	0.31	0.229
		Search	-0.12	0.29	0.975
		Overhaul	1.71	0.25	0.000
	Ventilation	Attack	-0.58	0.31	0.229
		Search	-0.71	0.31	0.115
		Overhaul	1.12	0.28	0.004
	Search	Attack	0.12	0.29	0.975
		Ventilation	0.71	0.31	0.115
		Overhaul	1.83	0.26	0.000
	Overhaul	Attack	-1.7	0.25	0.000
		Ventilation	-1.1	0.28	0.004
		Search	-1.8	0.26	0.000
Heart Rate	Attack	Ventilation	8.3	3.12	0.040
		Search	-9.1	2.96	1.229
		Overhaul	8.6	2.56	0.004
	Ventilation	Attack	-8.3	3.12	0.040
		Search	-17.5	3.20	0.000
		Overhaul	0.3	2.83	0.000
	Search	Attack	9.1	2.96	0.012
		Ventilation	17.5	3.20	0.000
		Overhaul	17.7	2.66	0.000
	Overhaul	Attack	-8.6	2.56	0.005
		Ventilation	-0.2	2.83	1.000
		Search	-17.7	2.66	0.000
% HR max	Attack	Ventilation	4.7	1.76	0.040
		Search	-3.5	1.68	0.150
		Overhaul	5.5	1.45	0.011
	Ventilation	Attack	-4.7	1.76	0.040
		Search	-8.2	1.81	0.000
		Overhaul	0.7	1.60	0.966
	Search	Attack	3.5	1.68	0.150
		Ventilation	8.2	1.81	0.000
		Overhaul	9.0	1.50	0.000
	Overhaul	Attack	-5.5	1.45	0.001
		Ventilation	-0.7	1.60	0.966
		Search	-9.0	1.50	0.000

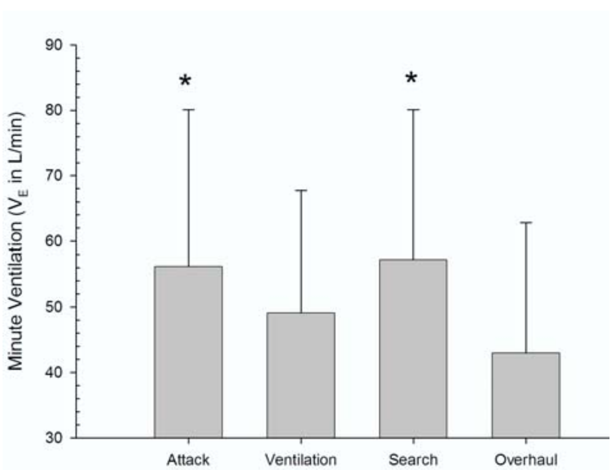
Graphs 6.1 through 6.5 illustrate differences in tidal volume, minute ventilation, physical activity (AccM, heart rate, and %heart rate maximum observed between Overhaul operations and suppression operations work phases. These physiological measures were all higher during suppression operations than during Overhaul.

Graph 6.1: Tidal Volume differences among Suppression and Overhaul Ops



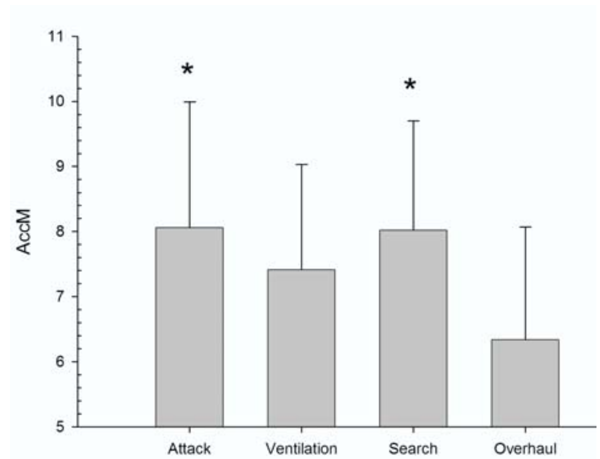
(*) Search VeVol > Overhaul, Attack VeVol > Overhaul

Graph 6.2: Minute Ventilation differences among Suppression and Overhaul Ops



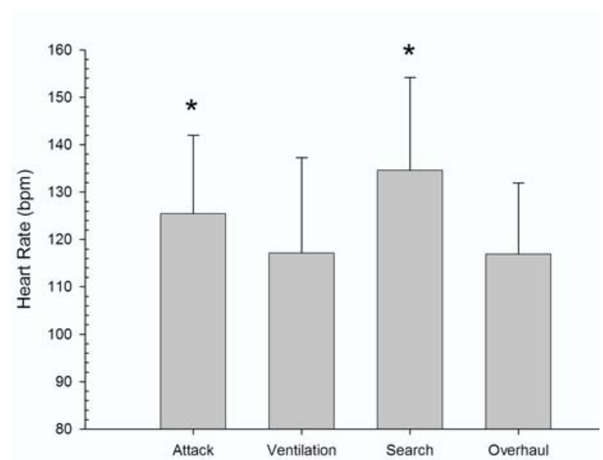
(*) Search V_E > Overhaul, Attack V_E > Overhaul

Graph 6.3: Physical Activity differences among Suppression and Overhaul Ops



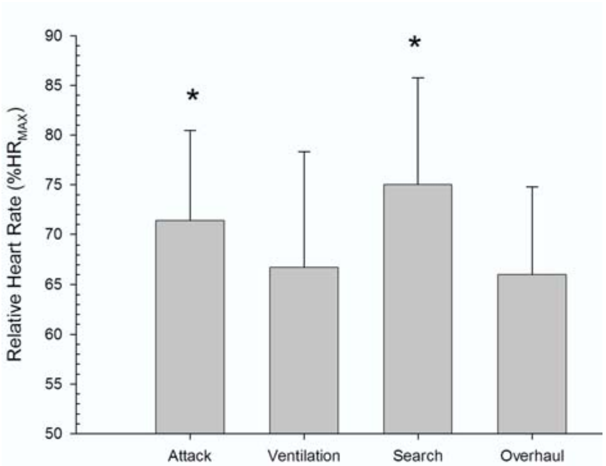
(*) Search AccM > Overhaul, Attack AccMl > Overhaul

Graph 6.4: Heart Rate differences among Suppression and Overhaul Ops



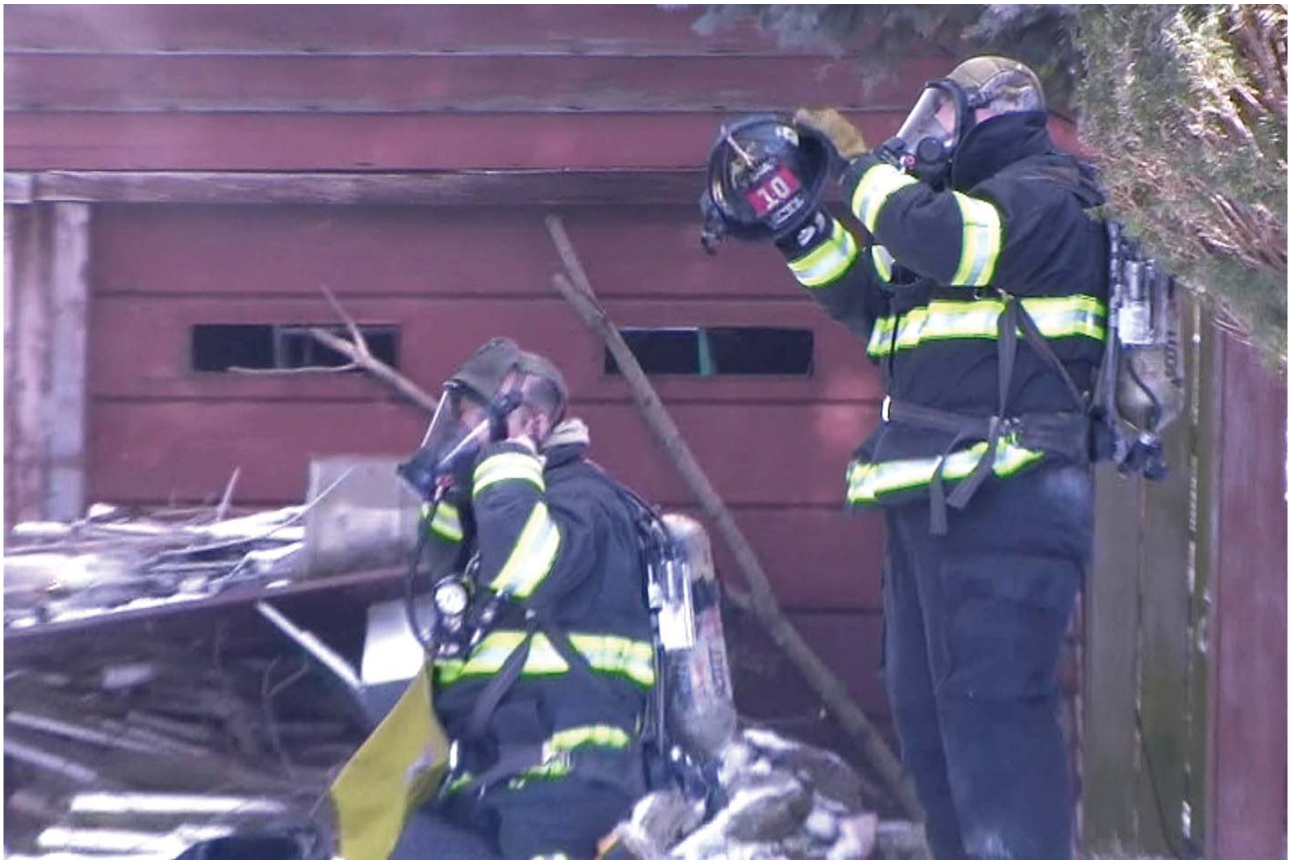
(*) Search HR > Overhaul, Attack HR > Overhaul

Graph 6.5: Relative HR differences among Suppression and Overhaul Ops



(*) Search %HRmax > Overhaul
Attack %HRmax > Overhaul

These data indicate that Overhaul operations imposed less cardiovascular and respiratory stress on studied firefighters than suppression operations. However, it is not possible to determine the relative contributions of psychological and physical stress that induce the observed responses. Overhaul can certainly be physically demanding work but it is generally executed in an environment of less psychological stress that suppression operations. Regardless of the stimulus (physical or emotional), increased heart rate generates cardiovascular stress.



Principle Components Analysis and Multiple Regression

A Principle Component Analysis was employed, to identify fire scene and subject characteristics having significant impact on firefighter physiology. Table 7.1 contains the component matrix extracted from the data set. This matrix was generated by pooling all fire scene and firefighter descriptive data and allowing the PCA analysis to group them into components. These components represent combinations of variables which explain the greatest variance in the cardiovascular physiology data.

The components listed in this matrix produced Eigenvalues above 1.0 as demonstrated by Graph 7.1. These Eigenvalues represent a weighting of variables with respect to their ability to explain variance in the dataA Principle Component Analysis was employed, to identify fire scene and subject characteristics having significant impact on firefighter physiology. Table 7.1 contains the component matrix extracted from the data set. The components listed in this matrix produced Eigen-

Table 7.1: PCA Component Matrix

	Component			
	1	2	3	4
Color	0.864	-0.105	0.029	.077
Involvement	0.830	-0.304	-0.053	0.155
Volume	0.805	-0.386	-0.026	.063
Situation	0.793	-0.394	0.074	-0.014
Heat Index	0.563	0.814	0.036	0.096
Temperature	0.573	0.808	0.038	0.088
% Body Fat	-0.121	-0.071	0.793	0.275
Age	-0.038	0.002	0.785	0.209
Footage	0.397	0.095	0.092	-0.653
VO2max	-0.056	0.016	-0.499	0.644

The Scree plot shown in Graph 7.1 indicates that only the first four solution components generated through PCA resulted in Eigenvalues greater than 1. Variables contained in the extracted components explain a total of 78% of observed physiology data variance and were therefore selected for Multiple Regression analysis

Graph 7.1: Eigenvalue Scree Plot

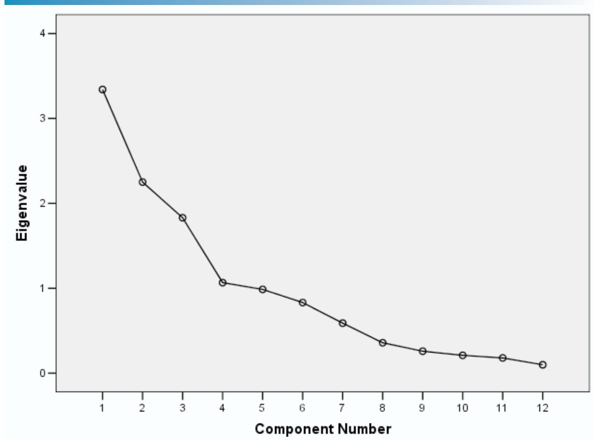


Table 7.2: Total Variance Explained

Total Variance Explained		
Component	**% Variance**	**Cumulative % of Variance**
1	35.3	35.3
2	17.4	52.7
3	15.1	67.8
4	10.1	77.9

Multiple Regression

Variables comprising the PCA-extracted components were regressed on a measure of cardiac stress (%HR_{MAX}). Table 7.3 contains the overall F-table for the regression and indicates a significant regression equation was produced.

Table 7.3: Multiple Regression F-table

ANOVA					
Model	**SS**	**df**	**MS**	**F**	**Sig**
Regression	7005.0	10	700.5	5.31	.000
Residual	67240.1	510	131.8		
Total	74245.2	520			

Examination of the coefficient table (Table 7.4) indicates five of the variables entered into the regression resulted in a significant regression equation.

Table 7.4: Standardized Regression Coefficients

		Beta Wt	F	sig
Model	(Constant)		4.58	0.000
	Age	0.218	1.38	0.007
	Yrs of Exp	-0.109	-0.68	0.252
	% Body Fat	-0.103	-1.24	0.003
	VO2max	.065	0.83	0.002
	Sq Footage	-0.078	-0.99	0.009
	Situation	0.132	1.12	0.264
	Involvement	0.139	1.06	0.002
	Color	0.133	1.10	0.105
	Volume	-0.075	-0.60	0.190
	Temperature	-0.006	-0.72	0.471

Table 7.5: Regression Model Summary

	R	R^2	Adj R^2	SEE
Model	0.317	0.100	0.048	10.44

Regression Equation

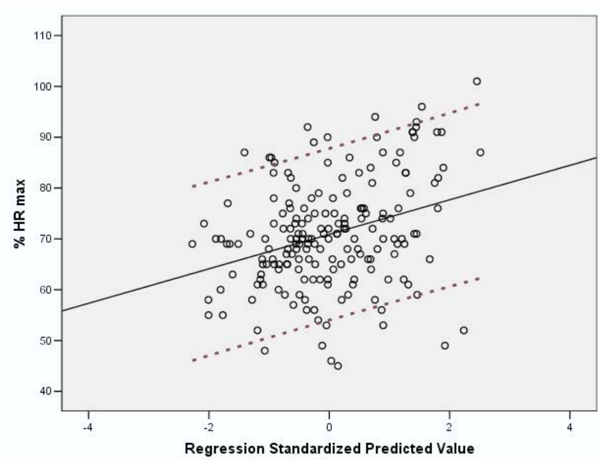
Significant variables from the coefficient table comprise the regression equation:

$$\%HR_{MAX} = 61.402 + (A * 2.335) - (B * 0.153) - (C * 0.310) - (D * 0.257) + (E * 0.000442)$$

A = % of Structure Involved in Fire
B = Firefighter Years of Service
C = Firefighter % Body Fat
D = Firefighter Vo_{2MAX}
E = Square Footage of Structure

The regression solution produced a predictive equation capable of estimating a firefighter's heart stress on a fire scene. The equation developed does not explain enough variance in the data set to be a practical predictive tool. However, the equation does identify and rank the fire scene and firefighter physiological variables that have the greatest impact on firefighter cardiovascular stress. Essentially a firefighter's age and fitness level combine with structure size and fire involvement to determine a fire scene's potential for inducing firefighter cardiovascular stress.

Graph 7.2: Regression Solution Estimating %HR_{MAX}



Qualitative Biomechanical Analysis

General Considerations

Thermal imaging and other video formats were utilized to observed firefighters during both real-world fire operations and during training. These video images were used to analyze the mechanics of firefighting skills. The physiological impact of these skills was interpreted to put the physiology recorded with LifeShirt into perspective. Personal Protective Equipment worn by firefighters is bulky and relatively heavy. In combination with the Self-Contained Breathing Apparatus (SCBA), hand tools, ladders, or hoses, the typical firefighter can carry as much as 70 pounds of gear onto the fire ground (Table 8.1). As a result, firefighters are almost immediately dependent upon glycolytic metabolism during suppression and overhaul operations.

In addition to the weight-bearing stress, firefighters also wear bulky gloves and ill-fitting boots which contribute to body instability. As a result, firefighters must exert greater than normal muscular

Table 8.1: Gear Weights

	N	Min	Max	Mean	STD
Weight (lb)	56	132.3	321.7	200.8	34.1
Wt w/gear (lbs)	56	203.7	434	272.5	38.8
Gear Wt (lbs)	56	49	112.3	71.7	14.6

Fire Attack Operations

Personnel involved in fire attack handle heavy, water-charge hose lines in an environment that typically requires them to assume a squatted or crawling body position. This body position and the forces required to move and manipulate the hose line results in large forces being generated, primarily by the body's core back, abdominal, and chest musculature. This type of movement and near-static force production typically results in elevated blood pressures due to a large magnitude of vascular compression.

Figure 8.1: Line Advance in Stairwell

Search & Rescue Operations

Search and rescue operations are generally conducted in low-visibility, high-heat conditions. The goal during primary search operations is to move as quickly as possible through the structure while still being thorough. In the effort, the firefighter carries a set of "Irons" weighing approximately 40 pounds in addition to their PPE and SCBA. Body positions assumed during search can be similar to that seen in Fire Attack. However, less force production is generally required to move through the structure. When search results in victim rescue, the firefighter must move the full body weight of a flaccid individual. This chore can be extremely difficult and require the generation of very large forces, primarily from the body's core musculature. Again, this force production and movement pattern can generate large insults to blood pressure due to vascular compression.

Figure 8.3: Laddering Up

External Ventilation Operations

Exterior ventilation operations often involve the use of ladders and tools to open windows or roofs to control heat and smoke movement within the structure. Firefighters typically carry chainsaws and other hand tools up ladders and then use them to cut holes through roofing material. Trying to maintain balance while operating a chainsaw off of a ladder lain across a steep roof, presents a significant challenge to the firefighter's agility. To maintain balance, it is necessary for the firefighter to have significant core body strength and endurance. Again, this type of near static work can cause significant increases in blood pressure. Figures 8.3 and 8.4 represent examples of exterior ventilation operations.

Figure 8.4: Opening a Roof

Overhaul Operations

Overhaul operations may involve work as strenuous as that of suppression and often more strenuous. The one overriding factor that reduces the cardiovascular stress during Overhaul is the reduced emotional drive (adrenaline) compared to suppression operations. The use of heavy tools and lifting make overhaul work similar to that seen in Ventilation. However, shoveling and lifting movement can cause substantial increases in blood pressure.

Figure 8.5: Overhaul

DISCUSSION OF FINDINGS

DISCUSION OF FINDINGS

Despite considerable effort to reduce line of duty deaths due to heart attack, sudden cardiac death remains the leading cause of on-duty firefighter fatalities. A more telling fact is that an estimated 765 on-duty firefighters experienced heart attacks in 2005 (43); only 62 (8.1%) of which resulted in sudden death (2). These data indicate an alarming rate of adverse cardiovascular events among firefighters. Recently, Kales et al reported that nearly all working firefighters succumbing to heart attacks were determined to have underlying cardiovascular disease (5). In support of this opinion, several studies have reported the presence of risk factors for cardiovascular disease in firefighters (8-14). The presence of risk factors or even cardiovascular disease alone does not however, explain the extraordinary rate of heart attack death in firefighters. In addition, it is apparent that these fatal heart attacks are occurring in individuals younger in age than those in the general public experiencing the same fate (1). At the very least, firefighting presents a significant trigger for cardiovascular events. Several studies have suggested that strenuous physical activity on the fire ground may serve as this trigger (5-7). Although firefighting is intuitively a highly physical undertaken, there is little or no data illustrating the magnitude of its physical demand. This current study was undertaken to elucidate the magnitude of the cardiovascular and respiratory stress associated with structural firefighting.

PHYSIOLOGY OF STRUCTURAL FIREFIGHTING

Alarm Response

The cardiovascular and respiratory stress of fighting structural fires begins with a firefighter's response to the fire alarm. Increases in heart rate and minute ventilation in response to the alarm are induced by two primary mechanisms. First, a sympathetic- nervous-system-induced catecholamine (adrenaline) release results in increased ventilation and heart rate even before movement begins. Second, as the firefighter begins to move toward an apparatus, physical movement further increases heart rate and ventilation. We examined the first 90 seconds following alarm to determine the magnitude of this response. Heart rates typically rise to near 80% of predicted heart rate maximum and subsequently begin to decline when the firefighter has donned his PPE and mounted the apparatus. The magnitude of these responses indicate that the combination of physical and emotional effort result in substantial cardiovascular and respiratory stress. Some studies have found this instantaneous effort can induce ECG arrhythmias (18, 21) in addition to the heart rate and ventilatory stress. Fortunately, these responses can be modified. Our data indicate that older firefighters and firefighters who possess better physical fitness have lower heart rate responses to the alarm.

Fire Ground Ingress

During ingress to the typical fire scene, firefighter physical movement is substantially reduced resulting in a decline in heart rate and ventilation. If the firefighter has or receives information suggesting the fire scene involves entrapped victims, heart rate and ventilation remain high (or even increase). High heart rate and ventilation during this period of reduced physical activity indicate a strong emotional influence induced by sympathetic outflow (adrenaline release). Ingress physiological responses can also be mitigated by firefighter age and experience as well as fitness. Our data indicate that older, more experienced firefighter and those who possess better physical fitness have substantially lower heart rates during ingress regardless of the circumstance.

Suppression Operations

Once on scene, firefighter activity is primarily determined by the phase of suppression operations in which they are participating. Standard operating procedures of the Indianapolis Fire Department define three distinct phases of suppression operations, Fire Attack, Ventilation, and Search & Rescue.

Fire Attack Operations

As defined by this study, fire attack operations began when the first arriving engine company marked on scene. Just prior to arrival (end of Ingress), heart rate and minute ventilation begin to rise due to anticipation. This anticipation is generally induced when the firefighter gains site of the burning structure. It is proportional to the firefighter's perception of fire volume and intensity and is graded with respect to the firefighter's age, experience and level of fitness.

Heart rate and ventilation increase significantly as work begins. Increases to accommodate initial work tasks, pulling hose lines, donning SCBA and moving into a structure, are accompanied by a sympathetic outflow (adrenaline). A portion of this outflow is normally associated with the physical workload. However additional outflow is present as an emotional response to the situation. As the hose team enters the structure and assumes a squatted or even crawling body position, the hose line is charged and the line is advanced toward the fire. Advancing the line in a squatted or crawling position requires activation of a large mass of core body musculature in near static contraction. This large muscle mass compresses vasculature and induces an increase in systolic and diastolic blood pressures. Elevated blood pressure in conjunction with an increasing heart rate cause increases in work of the cardiac muscle and result in an increased demand for cardiac blood flow. This high level of demand for cardiac blood flow and the increased pressure load on the heart could serve as a trigger for MI in an at-risk heart.

Another source of cardiovascular stress is introduced here. As the firefighter enters a burning structure, ambient air temperatures are severely elevated. Although the firefighter is somewhat protected within the PPE, the PPE itself represents an uncompensible heat stress environment, in which it is virtually impossible to lose body heat. This thermal stress induces a hear rate increase in an attempt to rid the body of heat. Profuse sweating occurs within the PPE. If this heat stressed environment is endured long enough, loss of body water results in a reduced blood volume and a concomitant increase in heart rate. Although no association was detected between heart stress during fire attack and the level of firefighter aerobic fitness, it is well established that improved aerobic fitness improves cardiovascular performance in uncompensible heat stress environments (46).

Structure Ventilation Operations

Ventilation operations, as described here, involved the exterior ventilation of a burning structure. In accordance with IFD standard operation procedures, exterior ventilation is begun by the outside team of the first arriving ladder company. The physical demand of Vent operations vary greatly with the method of ventilation executed (vertical vs. horizontal ventilation etc), and the size and type of structure involved (residence vs. commercial structure, one vs. two story etc.). During the study, the most common situation involved vertical ventilation of a single story, wood framed residential structure. Firefighters executing vertical ventilation on these structures were required to scale ladders, and use hand tools and chain saws. When doing so, these individuals can typically carry 40-50 pounds of tools in addition to wearing their PPE. Scaling a ladder carrying hand tools and saws requires substantial power output. This level of power output is energetically supplied by oxygen-independent metabolic mechanisms (glycolysis, and creatine phosphate systems). This type of non-oxygen-dependent work indicates a need for firefighters to possess substantial anaerobic capacity in addition to aerobic capacity. During ladder ascent, especially with tools, large masses of core body musculature plus arm and leg muscle are activated. Here again, the activation of large muscle masses in near static contractions increase rate pressure product and work of the heart.

Search & Rescue Operations

Search operations *can be* the most physically and emotionally stressful job on the fire ground. The goal of primary search operations is to quickly survey the interior of a structure for the presence of victims. Execution of a search pattern requires the firefighter to crawl throughout an unfamiliar, burning structure without aid of visibility. While on their knees, searching firefighters use one hand to maintain contact with the structure floor as well as probe the floor area with a hand tool. The opposite hand is used to navigate the structure by maintaining contact with a wall. The intention is to investigate as much of the structure area as possible, as quickly as possible. This is a lifesaving operation and is usually the only hope of an entrapped civilian to survive their situation. Despite the similar body positions utilized in search operations and in fire attack (crawling, squatting etc), the physiological responses of the two movements are different. Of course, both are physically demanding and result in significant increases in heart rate and minute ventilation. However, the fast-pace character of search results in significantly higher heart rates and ventilation compared to the hose line operations of fire attack. Although activation of core and limb musculature is required during search, the contractions are less static in nature and should not result is much increase in rate pressure product as that seen during fire attack. In addition, the duration of search operations here tended to be less than the other phases of suppression operations.

With the discovery of a victim, search operations turn into rescue operations. Rescue operations elevated firefighter physiology to an entirely different plane. As discussed earlier, the suggestion of potential entrapment elevated heart rates and ventilation during ingress to the fire scene. Discovery of a victim and the subsequent removal of the victim resulted in the most severe level of stress observed during this study. Both the physical and emotional components of stress combine to drive heart rates to more than 100% of what would be predicted as a firefighter's maximum. The physical demand of moving an unconscious person is enormous. Near maximal effort from large muscle mass is required to move an unconscious adult victim. This effort is generally executed in a crawling or squatted body position and can result in large increases in blood pressures. In addition to the physical effort, a large, emotionally-driven sympathetic outflow of adrenaline is present which drives heart rates to extreme levels. Most impressive however, is this level of stress may be maintained throughout a 20-30 minute rescue operation. During one rescue operation recorded here, 4 firefighters rescued multiple victims from a second floor bedroom. All 4 firefighters worked at or above their maximum predicted heart rate for more than 25 continuous minutes. The workload placed upon the hearts of these firefighters was enormous. They ranged in age from 34 to 54 years of age. Fortunately, none of the participating firefighters experienced adverse physical damage as a result of the operation. It is important her to note that these individuals area all extremely fit, highly trained, and experienced firefighters. Another firefighter lacking any of these traits would not have been able to execute the rescue and may have even died in the attempt.

Overhaul Operations

Overhaul work was defined here as anything from pulling ceiling, searching for extension or hot spots to recovering tools and hose lines. In general, overhaul work can be physically demanding but it is not generally executed in a threatening environment. In addition, the firefighter does not wear the SCBA for a large portion of overhaul work. Heart rate and minute ventilation are generally elevated but not to the extremes seen during suppression operations. This is most likely die to the reduced sympathetic outflow stemming from emotional distress.

Primary Determinants of Physiological Response to the Fire Scene

Impact of Study Design

Many factors play a role in determining how a firefighter responds physiologically to a particular fire scene. Factors such as age, years of experience, health status and measures of physical fitness, are specific to the individual firefighter. Other factors, such as weather, characteristics of the structure, command strategies, and time of day are determined by the fire scene. By selecting a specific time of year, a single department (with consistent tactics), and a specific fire coverage area (as determined by station selection), we loosely controlled many of these determinants. The city of Indianapolis provided a moderate climate during which, winter months limit the impact of ambient heat stress. In addition, the Indianapolis Fire Department is a large, professional organization with a reputation of using aggressive interior attacks to protect life and property of the citizens of Indianapolis. IFD adheres to NFPA standards for medical oversight of firefighters (NFPA 1500), providing a subject population of generally healthy individuals. Lastly, the selection of specific IFD stations focused the study on approximately 25 square miles of primarily wood-framed residential structures of less than 3000 square feet.

Identifying Physiologically Important Variables

Using a Principle Components Analysis coupled with multivariate regression, five variables or "factors" were identified that have the greatest impact on firefighter cardiovascular performance on the fire scene. These factors can be grouped into two categories based upon the firefighter's ability to modify them. A factor that is modifiable may be manipulated to alter the firefighter's cardiovascular response to the fire scene. If a factor is non-modifiable, the firefighter has no opportunity to change the factor in order to alter their physiological response.

The non-modifiable factors identified as having primary importance to firefighter physiology on the fire ground include the firefighter's years of service, square footage of the burning structure, and the portion of the structure involved in fire. Again, these factors are beyond control of the individual firefighter. More importantly, they set the fire scene's level of physical demand. Modifiable factors important to physiology were firefighter body fat percentage and firefighter aerobic capacity. On the fire scene, these modifiable factors determine how the firefighter will respond to the physical demand required to perform successfully. Both of these factors are health-related components of physical fitness and can be directly affected by the firefighter. Oddly, the equation indicates a negative relationship between body fatness and cardiovascular stress. This indicates that, within the studied group, cardiovascular stress was reduced as body fatness increased. So, does being fatter reduce stress on the heart? Of course, the answer is no. Recalling that the group studied here was a healthy and fit group of firefighters, increased body fatness actually reduced the firefighter's ability to work hard. Essentially, the firefighters with the highest levels of body fatness were simply not able to push themselves (physically) as much as their leaner counterparts. This effect may be unique to the group of individuals studied here.

CONCLUSIONS

CONCLUSIONS

It is no surprise that heart rates, minute ventilation and blood pressures are elevated during firefighting activity. The physical work demand and the emotionally charged environment require these responses. However, prior to this study, the magnitude and duration of these responses were unclear.

Annual reports of firefighter deaths (1, 2, 3, 4) generally list the cause of on-duty heart attack deaths as "overexertion". However, overexertion is a relative term. Levels of work that produce overexertion in one individual might not do so in another, more fit individual. Therefore, several factors must be considered to put the data presented in to context. When we report means or averages of heart rates (70% of predicted HRmax) and levels of minute ventilation (50 L/min), some of the work does not seem all that strenuous. However, firefighters studied here were highly trained, medically supervised, healthy and relatively fit individuals. The same work in a less well trained and less fit group of firefighters would result in much higher levels of cardiovascular stress. In fact, work here that pushed studied firefighters to 100% of their maximal cardiovascular capacity could not be accomplished by some unhealthy and unfit firefighters. Even within this group, we see individuals with higher levels of body fat not being able to work as hard as their leaner peers. Another factor to consider is the fires themselves. We saw from the principle components analysis, the size of the structure and amount of fire involved have significant impact on the firefighter's response. Indeed, the average structure studied was a relatively small (2500 ft^2) residential structure. As structures grow larger and more complex, the physical response grows. Yet, even some of these small structures pushed firefighters to their maximal abilities. Lastly, we must consider the weather conditions. We chose to conduct the study in the absence of ambient environmental heat stress. Unfortunately, firefighters must fight fire in all weather conditions, including hot humid weather that imposes extreme heat stress conditions on the fire scene. The process of thermoregulation can impart severe cardiovascular stress on firefighters before they set foot on the fire ground. During a 2005 study of training related physiology, a study conducted at the Maryland Fire and Rescue Institute (36) saw many firefighters reporting for duty in a dehydrated state. Dehydration exacerbates the cardiovascular stress associated with thermoregulation and can debilitate even the most fit firefighter.

Fire Scene as a Trigger for Heart Attacks

So, how does the information presented here shed light on the extraordinary number of firefighter line of duty heart attacks? The answer lies in the magnitude of the physiological responses. Recently, a comprehensive examination of the LODD due to heart attack was completed by a group at Harvard University (5). The researchers found the primary cause of heart attack deaths associated with firefighting was overexertion in firefighters with existing cardiovascular disease. A 2006 review of research on cardiac deaths indicated that high levels of physical exertion as well as severe emotional stress are triggers for a heart attack (47). In the case of firefighters, both physical and emotional triggers are present. These researchers also concluded that periods of high physical or emotional stress essentially accelerate an inevitable cardiac event in persons with cardiovascular disease. This is an extremely important point with respect to firefighters. One of the most alarming facts with respect to on-duty firefighter heart attack fatality is the average age at the time of death is in the early 4th decade of life.(1). If you are a person with cardiovascular disease, death due to heart attack or stroke is probably inevitable. However, if you are a firefighter with cardiovascular disease, that death due to heart attack or stroke is likely to come *much sooner*.

Another question asked about firefighter line of duty heart attack deaths is why so many occur *after* leaving the fire scene. As discussed earlier, there is an essential physical recovery period following any physical activity. The duration of the recovery period is determined by the duration and magnitude of the physical activity combined with the individual's level of aerobic fitness (all recovery is aerobic). This is because physical activity raises body temperature and causes the release of many hormones that enable us to do high levels of work. One of these hormones, adrenaline, is also released in response to emotional stimuli. Adrenaline raises the heart rate, blood pressure and increases minute ventilation. The higher the physical demand or emotional stress, the greater the rise in temperature as well as the amount of hormone released. These factors do not simply disappear with the cessation of physical activity or the removal of an emotional stimulus. Substantial time is required to metabolize hormones and to dissipate heat. As a result, stress effects tend to linger. One incident captured by the study involved the rescue of children entrapped on the second floor of a fully involved residence. The incident resulted in severe physical and emotional stress on the firefighters driving heart rates to levels in excess of 100% of their predicted maximum. Two hours after returning to station (some three hours following the completion of rescue operations), heart rates of individuals involved in the rescue remained in excess of 100 beats per minute. Essentially, the physical and emotional triggers for heart attack stay with the firefighter for some time after an incident. High levels of stress present long after an incident, is a potential trigger for cardiovascular events, especially in individuals with underlying cardiovascular disease.

Reducing Firefighter Deaths Due to Heart Attack

Unfortunately, many firefighters in the US are not only unfit for fire scene work but are generally unhealthy individuals. The discrepancy between the physical preparedness of firefighters and the high physical demand of firefighting stands at the center of fire service line of duty deaths. Simply to expect to survive fire ground operations, a firefighter needs, as a minimum, to be healthy (including the absence of cardiovascular disease). The goal of this research is to support a service-wide effort to reduce the number of firefighter line of duty deaths. Because heart attacks account for nearly half of these deaths, much attention is focused on elucidating and eliminating the cause of these events. Unfortunately, no substantial improvements in firefighter health have occurred in the last 25 or so years. As a result, firefighter death statistics (as a result of heart attack) remains virtually unchanged. With improved research funding we are beginning to better understand the etiology of these events and to develop plans that will change the death statistics. Currently, there appear to be two primary approaches to the problem.

Some researchers are working on the development of physiology monitoring systems in hope of detecting severely elevated cardiovascular or respiratory responses during fire ground operations. This in turn would allow affected firefighters to be relieved before a catastrophic event is triggered. Unfortunately, the data presented here suggest this approach would not be successful. It is apparent that, in some cases, extreme physiological responses are appropriate on the fire ground. Simply removing a firefighter because his or her heart rate is extremely high would stand in the way of getting the job done. It is much more important that firefighters be healthy and fit enough to turn the output of their cardiac pumps up (increase heart rate) enough to do what they are expected to do and not experience adverse effects because of it. This seems to negate the utility of a monitoring device that simply alerts to extreme level of heart rate or ventilation.

Programs such as the Wellness/Fitness initiative undertaken by IAFF and IAFC, and the US Fire Administration's Life Safety Summit have recognized the need for improving the health of firefighters as a preventative measure. The national fire prevention association has issued guidelines for oversight of firefighter health programs (31). These programs set the stage for improvement in firefighter health. If successful, they will certainly result in a reduction in firefighter deaths due to heart attack. It is important however, that firefighters take advantage of such programs, either voluntarily or as a requirement for service.

Although there remain unknown factors on the fire ground that may increase a firefighter's risk of developing heart disease, we know now that the vast majority of heart attack deaths occur in unhealthy, unfit firefighters. This study clearly demonstrates the magnitude of cardiovascular stress placed on working firefighters and indicates firefighting activity can be a trigger for a cardiac event. Essentially, firefighting is triggering a cardiac death that is inevitable in persons with cardiovascular disease. So how do we stem the tide of heart attack deaths in working firefighters? We must improve firefighter health and reduce their risk factors for heart disease. Whether the responsibility for that improvement lies with the firefighter, their department or their labor organizations is for the fire service to decide. The fire service is still asking why are firefighters dying of heart attacks and what can we do about it. Academic researchers have been demonstrating since the mid-seventies (6-11, 13, 15-24) that firefighting is a substantial trigger for heart attack and preventative physical training should be *required* of firefighters.

Implications for Firefighter Physical Training

Development of an effective physical training program begins with the identification of demand levels a job or event presents. Several studies have attempted to quantify the physical demand of firefighting by observation of training or simulated firefighting activity (6, 15-16, 18-27, 36, 38, 46). Unfortunately, laboratory measures tell us little about the physiology of real world structural firefighting. This was a primary reason the current study was undertaken. Adequate funding, appropriate technology, and an embedded relationship with a large metropolitan fire department enabled us to examine the physiology of real-world firefighting. With information about the cardiovascular and respiratory demands of structural firefighting, we are now able to make statements about how firefighters should be trained.

First, it is important to define what we refer to as physical fitness. The terms healthy and physically fit are not synonymous. Healthy refers to a state of well being and includes both physical and emotional aspects of life. Physical health includes not only the absence of disease but several functional physiological capabilities commonly referred to as health-related components of physical fitness. These components include aerobic capacity, body composition, muscular strength, muscular endurance and flexibility. Sound physical training programs designed for the general population address all of these components. Programs designed for individuals who regularly endure high levels of physical stress go beyond these health-related components and include some performance-related components of physical fitness. In addition, the goals for health-related components are substantially different for these individuals compared to the general public. Athletes and firefighters fall into this higher-demand category. Sometimes you will even hear firefighters referred to as occupational athletes.

The cardiac and respiratory stress data, in combination with the inferred blood pressure responses described by this study, elucidate the firefighter's need for a healthy cardiovascular system. The firefighter cardiovascular system will be stressed significantly, sometimes under high ambient heat stress conditions. In addition, the need to exert and maintain large muscular forces, usually from an awkward body position, indicates the need for significant muscular strength, muscular endurance, and joint flexibility compared to civilian counterparts. Accordingly, standardized guidelines for physical training NFPA 1583 (49), address these components for developing the firefighter's physical fitness. As fire scene work begins, firefighters typically carry 60-70 pounds of protective clothing, breathing apparatus, and tools. As a result, little of the work executed on the fire ground could be described as having a large aerobic component. Instead, the high levels of power output required on the fire ground places emphasis on non-oxidative (anaerobic) metabolic processes. This anaerobic capacity is not considered a health-related but a performance-related component of physical fitness. An improved anaerobic capacity can significantly reduce cardiovascular stress in individuals executing anaerobic work. Accordingly, firefighters would benefit from training that improves glycolytic and creatine phosphate metabolic system capacities.

Other performance-related components of physical fitness also play a role on the fire ground. Studies conducted by Dr. Denise Smith (50. 51) have shown the effects of firefighting activity on the balance and coordination of firefighters. Training protocols that include agility training would also benefit the firefighter and alleviate some of the risk of trips and falls on the fire ground, a substantial origin of firefighter injury.

Lastly, it is important (from a physiological standpoint) to recognize the wide range in numbers of fires worked between fire service organizations and the effect is has firefighter physical demand.

The physiological demand required to fight a structural fire is primarily determined by the structure. Essentially, the structure sets the demand level without regard to who is coming to fight the fire (career professional, volunteer, paid volunteer etc). As such, achieving similar goals on the fire ground places the similar physical stresses on *all* firefighters. However, a firefighter working in a busy company of a large metropolitan department may be required to fight multiple fires in a single shift. This lies in sharp contrast to the rural unpaid volunteer who may only work a handful of structural fires in a year. As observed in this study, the physical stress placed on the firefighter does not simply disappear when they leave the fire scene. Significant cardiovascular stress may be present for some time following an incident. Unfortunately, this places a substantial burden on firefighters who fight large numbers of fires. These firefighters do need to be held to a higher standard of physical preparedness in order for them to recover quickly and be able to meet the demands of the next incident. Achieving a level of physical preparedness that enables the firefighter to survive and function appropriately on a fire scene should be the *starting point* for firefighter physical training, not the goal!

As always, the healthier and more physically fit *any* firefighter is, the better. However, at a minimum, the firefighter needs to a healthy and physically fit *citizen*. With increasing physical stress (as determined by the number and character of fires they fight), higher fitness goals need to be set to ensure the firefighter is physically prepared. This would include increased levels of all health-related fitness components and the incorporation of performance-related components into physical training programs.

In conclusion, it appears that firefighting activity presents significant cardiovascular and respiratory stress. Recent evidence suggests that a majority of the cardiovascular-related line of duty deaths are caused by underlying heart disease. It is clear from the data collected here that fire scene work exposes the firefighter to a substantial potential for triggering cardiovascular events. Therefore, firefighters with pre-existing cardiovascular disease exposed to the physical and emotional stress of a fire scene are in extreme risk of a experiencing a myocardial infarction, stroke or other cardiovascular system collapse.

The fire scene is alive with many potential complicating exposure factors (toxic gases, particulates etc.) and it is certainly possible that working on a fire scene may contribute to the progression of the disease state. However, the best defense against the progression of the disease is a health monitoring plan coupled with a sound physical training program, and adequate operating procedures to lessen exposures. The National Fire Protection Association has issued guidelines for such programs and, in the case of physical training program, suggests they be made mandatory (49). Although this guideline meets with resistance from every faction of the fire service, departments, unions, and firefighters alike, it is a simple fact that sound physical training programs are the only way line of duty deaths due to heart attacks are going to be reduced.

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Appendix A:
Timeline of Physiological Responses

TIME	ELAPSED	EVENT	DESCRIPTION	SIGNIFICANT PHYSIOLOGICAL RESPONSES
0:30:00	0:00:00	Still Alarm	Report of a fire in a residence	Awaken HR and VE increase with increased physical activity and anticipation HR and VE are modified by fitness level and years of experience
0:31:20	:01:20	Exit & Ingress	No additional information	Initially,HR and VE decline with reduced physical activity Modified by firefighter experience and fitness Approaching scene, HR and VE increase with anticipation (adrenaline release
0:33:25	0:03:25	Arrive on Scene Size Up	Weather 8.3^{0}C (47^{0}F), 65% Relative Humidity Clear Sky, No Wind Double reidence Fire & heavy smoke showing from 1st floor 50% involvement, Gray smoke on arrival	Ingress companies: HR and VE Increase due to anticipation (adrenaline release)
0:33:25	0:03:25	Fire Attack Begins	Don SCBA & enter structure Advance hose line to fire	HR and VE increase exponentially as work begins HR increases to ~71% of predicted HRmax, VE increases to ~56 L.min In crouched position or kneeling with hose line, SBP and DBP increase RPP increases drastically as HR and SBP increase
0:33:25	0:03:25	Primary Search Begins	Don SCBA & enter structure Execute multi-room primary search	HR increases to ~75% HRmax and VE to ~57 L/min HR and VE may reach steady state and is maintained through search
0:33:25	0:03:25	Vertical Vent Begins	Retrieve tools approach structure Dom SCBA & Scale Ladder Vent Roof with chainsaw	HR and VE increase due to increased work level and adrenaline release HR increases to ~67%HRmax and VE increases to ~49 L/min If core body muscle is tensed to stabilize the body, blood pressure and HR increase drastically
0:45:37	0:15:37	Primary Search Ends	Exit Structure & change air bottle	HR and VE drops significantly
0:50:25	0:20:25	Vertical Vent Ends Exit	Roof prepare to deploy PPV fan	HR, VE and blood pressures decline to level appropriate to work load
0:52:25	0:22:25	Fire is Controlled		
0:52:25	0:22:25	Overhaul Begins	Search for hot spots & extension	HR and VE increase proportionally to work load Overhead work increases HR and VE moderately, SBP & DBP increase significantly Shoveling and other heavy lifting can also increase blood pressure
	Loss Stop			
1:12:00	0:42:00	Interior Overhaul Ends	Personnel exit structure Recovery of equipment and personnel	As heavy work ends, HR and VE decline to match workload
1:32:00	1:02:00	Exit Scene	Command Terminated	Physiological recovery begins; HR and VE decline as work load decreases
1:40:00	1:10:00	Return to Station		HR and VE remain elevated during recovery. EPOC is proportional to duration and level of exertion on fire scene Emotional stimuli may also contribute to elevation and delay return to pre-run levels

APPENDIX B:
INFORMED CONSENT STATEMENT

Study #: 07-12447

INDIANA UNIVERSITY – BLOOMINGTON
INFORMED CONSENT STATEMENT

EXAMINATION OF THE PHYSIOLOGICAL RESPONSES TO STRUCTURAL FIREFIGHTING AND PSYCHOLOGICAL RESPONSES TO GENERAL EMERGENCY CALL WORK SEEN IN PROFESSIONAL FIREFIGHTERS

You are invited to participate in a research study. The purpose of this study is to determine the physical and emotional responses of firefighters responding to emergency call and fighting structural fires. Sixty firefighters will be recruited for the study that will be conducted over 50 standard duty shifts (approximately 6 months).

STUDY INFORMATION

Medical History and Physical Assessment

To start the study, you will be asked to complete a demographic and medical history questionnaire that provides information about conditions that may affect your physical work performance. In addition, you will be asked to submit to a series of physical work tests to assess health-related aspects of your physical fitness.

Fitness Assessment

The first test, a Queen's College Step test, is designed to assess your cardiovascular fitness (condition of your heart and lung function). Before beginning the step test, you will be asked to put on a LifeShirt® device (described in detail below). This device will monitor and record your heart rate during the step test. Later, the research staff will use your heart rate during and after the test to evaluate your fitness level. To complete the test, you will stand at rest in front of an 18-inch tall box for two minutes. At the end of the rest period, you will be asked to step on to and off of the box for a period of three minutes. You will be provided with a cadence (rhythm) to step to during the test. At the end of the three-minute test period, you will again be asked to stand in front of the box for a period of two minutes to recover. Your pulse will be measured and recorded during the recovery period and used to estimate your cardiovascular fitness level.

.Subject Initials: ________

Next, you will be asked to do as many standard sit-ups as you can within a 2-minute period. This test is a field estimate of general muscular endurance. Third, you will be asked to do as many standard push-ups as possible within a one-minute period. This push up test is used as a general indicator of you muscular strength.

Physical Dimension and Body Composition

Your height and weight along with your waist and chest circumferences will be measured. To determine the amount of body fat you have, the thickness of skinfolds will be measured. Skinfolds are determined by measuring the thickness of a fold of skin pinched between the thumb and index finger. By measuring these thicknesses at specific body sites, the portion of your body that is fat can be estimated. Because all research team members will be males, females may refuse collection of body measurements that involve personal contact with a member of the research staff. Refusal will not prevent you from participating in the study.

Physiology Monitoring

During a period of fifty (50) consecutive duty shifts, you will be asked to wear a garment called LifeShirt® (Figure 1). This garment will continuously monitor your heart and breathing function as well as the movement of your body. The garment is a simple vest that zips up the front and contains two flexible wires to monitor breathing function. Three electrodes will be attached to your chest to record your Electrocardiogram (ECG or heart function). Prior to putting these electrodes in place, your skin will be prepared by wiping with an alcohol pad. A small disposable razor will be used to remove a small amount of hair at the attachment site if necessary.

With the vest in place, a single wire (called a data cable) that attaches to the ECG electrodes and the embedded wires will be attached to the front of the vest with Velcro®. The data cable connects to a small recording device you will carry in your pocket. Once the monitoring device is in place, it will be powered up and calibrated. You will be supplied with extra LifeShirt® vests and ECG electrodes so you may change when necessary. At the end of your duty shift, you will turn the recorder off and remove all monitoring equipment. You will then

.Subject Initials: ________

be provided a logbook in which you may record any information you feel important. LifeShirt® garments will be laundered by researchers and returned to you at the beginning of your next duty shift.

Figure 1: LifeShirt® system with recorder

Fire Scene Data Collection

A member of the research staff will be on duty during your duty shift and will be on-site at fire incidents to which you respond. At these fire scenes, researchers will observe and collect data that describes the environment in which you are working. This data collection may involve video recordings of you doing your job. This video data will be used to help researchers better understand and describe what you do. In addition, some video will be part of a final report given to the study's funding agency (US Homeland Security) as well as distributed to the fires service across the US.

Psychological Assessment

During a two-week period of the study, a randomly chosen group of 6 participants will be asked to provide additional information for the study. In addition to the physical data being collected, these individuals will be asked to fill out a short survey examining their emotional state at the beginning of their work shift and again after each emergency run (not just fire runs). At the same time the survey is filled out, you will be asked to provide a saliva sample by spitting into a sample tube. This saliva sample is used to measure your level of a stress-

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related hormone called Cortisol. If invited to participate in this phase of the study, you may refuse but remain in the primary study.

Data Analysis

Once all data is collected, researchers will use a statistical technique know as a principle components analysis to determine findings. This analysis allows researchers to determine the principle (most important) aspects (or components) of your job that determine how much physical stress you endure while fighting fires.

RISKS

Your participation in this study does not present any foreseeable risk to your health or safety. Some people have experienced slight discomfort when wearing the LifeShirt® garment due to skin sensitivities to fabrics or to electrode adhesives. Although these discomforts are rare and usually minor, it will be up to you to decide whether or not you wish continue in the study. The Queen's College Step test you will be asked to perform is a field test to determine your fitness level. Although less strenuous, it is intended to estimate the same information the doctor gets during your annual duty fitness stress test.

BENEFITS

As a result of your participation in the study, you will receive information from the research team about your physical fitness and body composition. At the end of the study, you will also receive copies of final study reports in both written and video format.

In a broader view, this project is a first of its kind study, which will provide researchers and the fire service with valuable information about the physical demands of your job. As a result, important advances may result which ultimately improve the health and safety of all first responders.

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CONFIDENTIALITY

It is important that you know how researchers deal with your personal information collected for the study. All information collected form you is strictly confidential and will not be disclosed to anyone outside the research team for any reason. Rather than using your name, you will be assigned a study identification number that will identify all data collected from you. Any paperwork that contains your name will be locked in a secure file cabinet for the duration of the study and destroyed after the study is completed. All data from individuals will be pooled (grouped) for analysis. As a result, it will not be possible for you or anyone else to identify your individual data in reports derived from the study.

At the end of the study (approximately May 2008), the code information that enables your identification will be destroyed. All the data (including video data) will remain in the possession of the researcher permanently.

COMPENSATION

As compensation your participation, you will receive $30.00 for each duty shift in which you are involved in the study. At the end of each duty shift, you will be asked to sign a log sheet. The log sheet will be counter-signed by a member of the research staff verifying your participation. Because you all live in different locations throughout the Indianapolis metro area, your local union office has volunteered to provide a secure and confidential drop box for your logs. You will need to deliver these logs to the local union office drop box in order to be paid for your participation. The research staff will collect these logs when it is time for payment to be made. Payment will be made to you twice, once at the study mid-point and once at the end of the study.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the researcher, Dr. Joel Stager, at 1025 East 7th Street, Bloomington, IN 47405, 812-855-1637, and stagerj@indiana.edu .

.Subject Initials: ________

APPENDIX B: APPROVED INFORMED CONSENT STATEMENT

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the office for the Indiana University Bloomington Human Subjects Committee, Carmichael Center L03, 530 E. Kirkwood Ave., Bloomington, IN 47408, 812/855-3067, by e-mail at iub_hsc@indiana.edu.

PARTICIPATION

Your participation in this study is voluntary; you may refuse to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed.

CONSENT

I have read this form and received a copy of it. I have had all my questions answered to my satisfaction. I agree to take part in this study.

Subject's signature______________________________ Date __________________

Consent form date: September 18, 2007, Revised: September 28, 2007, Oct 3, 2007.

IRB Approved
Approval Date: OCT 0 4 2007
Expires: OCT 0 3 2008

Page 6 of 6

Appendix C:
Institutional Review Board Approval

RECEIVED
SEP 21 2007
HUMAN SUBJECTS COMMITTEE

INDIANA UNIVERSITY
BLOOMINGTON CAMPUS COMMITTEE FOR THE PROTECTION OF HUMAN SUBJECTS

DOCUMENTATION OF REVIEW AND APPROVAL
of
Research Project Utilizing Human Subjects

Study # 07-12447

TITLE OF PROJECT: Examination of the Physiological Responses to Structural Firefighting Activity and the Psychological Responses to General Emergency Call Work Seen in Professional Firefighters

PROJECT DURATION - START DATE: ~~09~~ 10/07/2007   END DATE: 09/06/2008

PRIN. INVESTIGATOR: Dr. Joel M. Stager, PhD   SCHOOL/DEPARTMENT: HPER / Kinesiology

ADDRESS: 1025 East 7th Street, Bloomingotn, IN 47405   E-MAIL: stagerj@indiana.edu   PHONE: 812-855-1637

RANK: Faculty ⊙ Res. Scientist ○ Post-Doc ○ Staff ○ Student: undergrad ○ masters ○ PhD/EdD ○

If PI's rank is OTHER than faculty, name of faculty overseeing the research (SPONSOR) ____

SPONSOR'S E-MAIL ____ CAMPUS ADDR ____ PHONE ____

FUNDING AGENCY and #: US Department of Homeland Security, FIre Act Grant Application #: EMW -2006-FP-02258

As the principal investigator, my signature testifies that I pledge to conform to the following:

As one engaged in investigation utilizing human subjects, I acknowledge the rights and welfare of the human subject involved.

I acknowledge my responsibility as an investigator to secure the informed consent of the subject by explaining the procedures, in so far as possible, and by describing the risks as weighed against the potential benefits of the investigation.

I assure the Committee that all procedures performed under the project will be conducted in accordance with those Federal regulations and University policies which govern research involving human subjects. **Any deviation from the project (e.g., change in principal investigator, research methodology, subject recruitment procedures, etc.) will be submitted to the Committee in the form of an amendment for its approval prior to implementation.**

PRINCIPAL INVESTIGATOR:

Joel M. Stager — (typed/printed name)   [signature] — (signature)   Sept 21 2007 — (date)

As the faculty sponsor, my signature testifies that I have reviewed this application and that I will oversee the research in its entirety, through the termination report.

FACULTY SPONSOR:

____ (typed/printed name)   ____ (signature)   ____ (date)

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CAMPUS LEVEL REVIEW

This protocol for the use of human subjects has been reviewed and approved by the Indiana University/Bloomington Campus Committee for the Protection of Human Subjects.

____ Exempt Review ¶# ____, ____ Exempt ¶# ____ with signed/documentation of consent,

✓ Expedited Review ¶# 3,4,6,7 ____ Full Review, ____ Not Approved, ____ Withdrawn

[signature] Chairperson/Agent IUB Committee   10/4/07 Date

logged in ts 9/21/06 approval logged ✓ copy to PI 10/4/07 rank code FT1 Col 3/13/07

test: PI 10/5/06 sponsor ____ co-PI ____

3/07

INDIANA UNIVERSITY
BLOOMINGTON

School of Health, Physical Education & Recreation
Department of Kinesiology