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Frequency, Intensity, Time and Type of Tasks Performed during Wildfire Suppression

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Abstract

Objective: To quantify the frequency, intensity, duration, and type of tasks performed by Australian rural fire crews when suppressing wildfires.

Methods: Twenty-eight Australian rural firefighters worked across four, six-hour shifts fighting to curtail the spread of wildfire. Each firefighter wore a heart rate monitor and personal global positioning system (GPS) unit and was followed by a researcher filming their work activity. Video footage of each firefighter was synchronized with their heart rate and GPS data to quantify the frequency, intensity and duration of individual fireground tasks. Fireground tasks were isolated using a previously conducted job task analysis.

Results: Firefighters performed 32 distinct fireground tasks. Task frequencies ranged from once to 103 times per six-hour shift. Individual tasks lasted 4 ± 2 s to 461 ± 387 s, were performed at speeds ranging from 0.12 ± 0.08 $m\cdot s^{-1}$ to 0.79 ± 0.40 $m\cdot s^{-1}$ and elicited mean heart rates that ranged between 97 ± 16 $beats\cdot min^{-1}$ (55.7 ± 8.7 percentage of age-predicted maximum heart rate (HRmax)) and 157 ± 15 $beats\cdot min^{-1}$ (86.2 ± 10.8%HRmax).

Conclusion: Fireground tasks were, generally speaking, shorter, slower, and elicited lower heart rates than equivalent tasks previously simulated and reported in the literature. The differences between naturally occurring and simulated tasks question the value of isolated task simulations for conducting physical demands analyses en-route to developing job-specific fitness tests.

Keywords: Firefighters; Video analyses; Heart rate; Velocity

Introduction

Worldwide, firefighters protect urban and rural communities against fire. To support this fundamental civil service, researchers have spent the past 40 years quantifying, and where possible, mitigating the risks to firefighters' health and safety. Fundamental to all firefighters' health and safety research is the acute quantification of the physical demands faced by firefighters when on duty. To date, researchers have used a range of approaches to capture firefighters' task demands. These methods include; subjective job task analyses [1,2], physiological and (to a much lesser extent) biomechanical analysis of isolated firefighting tasks [3-7]. Time and motion analysis of larger scale emergency and simulated fire suppression [8,9] as well as remote monitoring of heart rate and energy expenditure during emergency fire shifts have also been conducted [10-15]. Though each approach advances our collective understanding of firefighters' work, limitations persist. For instance, job task analyses using subject matter experts, though effective at capturing operationally important tasks, yield highly variable recall of task frequency and duration [16-18]. Similarly, quantifying work intensity during isolated tasks simulations provides no insight into the frequency with which a task occurs or the duration of successive task repetitions on shift. Finally, whole shift measures of energy expenditure [19] or heart rate [12,13] are unable to isolate task demands in situ. Only two studies have used direct observation to characterize the inherent requirements of firefighting work. Budd et al. [9] recorded the frequency (though not clearly reported) and duration of Australian rural firefighters activities when working to suppress experimentally lit wildfires lasting 87 ± 42 min. Here, fireline construction and activity was measured every minute via direct observation. Thereafter, these investigators [9] used individual regression equations to extrapolate a firefighter's fireline construction rate to measures of energy expenditure. Real time physiological measurements to accompany task frequency and duration data were also reported, albeit in a separate study [20] and not synchronized to the individual tasks. Bos et al. [8] used the task recording and analysis on computer (TRAC; [21]) method together with wireless heart rate monitoring to quantify the frequency and duration of the physical tasks performed by Dutch urban firefighting during a 24-hr shift. Bos et al. [8] reported that urban firefighting can be characterised by a low frequency of incidents which were reported as short tasks with a moderate to occasionally high workload. As identified recently by Wyss and Mader [22] the benchmark study of Bos et al. [20] also have limitations. Firstly, heart rate has a delayed reaction to activity changes, a time lag which may translate into a lower than expected heart rate for an initial task in a sequence, or an inflated heart rate for subsequent tasks [22].Secondly, firefighters' heart rate on shift is likely to reflect the combination of the psychological and physiological demands of their job [23].Thirdly, reliance on TRAC without subsequent verification of activity recordings with video may reduce the precision of the activity classifications [22]. Indeed, the validity of direct observations, including TRAC has been questioned for dynamic manual handling tasks [24] such as those performed in firefighting work [1,2]. Wyss and Mader [22] advocated the use of video analysis to verify task analysis. These authors also used activity monitors to complement heart rate measures and capture immediate changes in body movements during physically demanding military tasks. Many activity monitors do not, however, have the resolution for very brief (<60 seconds) tasks. Portable global positioning systems (GPS) may be a valuable tool to capture movement velocity, which may be critical during specific tasks in emergency scenarios where urgency is paramount.

Relative to other fire jurisdictions, the physical activity profile of Australia's rural firefighters suppressing wildfire is poorly detailed. The lack of analyses is somewhat surprising given that Australia's rural firefighters defend one of the most wildfire prone regions on Earth, with catastrophic fires claiming 725 civilian (i.e., non-firefighter) lives since 1900 [25]. To date, our group has undertaken subjective job task analyses [2] and quantified oxygen uptake and heart rate during simulations of isolated tasks [26]. Collectively, these studies show that the wildfire suppression tactics used by Australian rural firefighters comprise a hybrid of the urban [5] and North American forestry [27] firefighting techniques used worldwide. The oxygen uptake and heart rate responses were comparable (if not marginally lower) than similar tasks in structural [3,4] and wildfire [4,28] firefighting contexts. None of these studies have quantified the frequency, intensity, time or type of tasks that firefighters perform when striving to protect the nation from wildfire. To this end the aim of the current study was to use video footage of individual firefighters wearing heart rate and GPS devices to quantify the frequency, intensity (heart rate and velocity), and duration of types of tasks performed by Australian rural firefighters whilst suppressing wildfires.

Methods

Participants

Twenty eight volunteer firefighters (22 males, six females) from the Tasmanian Fire Service (TFS), participated in the current study. All participants were from local brigades and were in operationally active roles. Firefighters were recruited to participate at one of four single-day wildfire incidents in dry eucalypt forest of North Eastern and South Western Tasmania. All testing was conducted in mild to warm temperatures (15 to 25°C). Recruitment occurred at firefighters' pre-shift briefings before they deployed to their normal work shift. Informed consent was obtained from each participant. Immediately thereafter, firefighters' personal demographics (i.e. age, years of brigade membership) was recorded and their body mass and height were measured using standard scales (A and D, Japan) and portable stadiometer (SECA, China), respectively.

Equipment

All participating firefighters were fitted with a portable 1-Hz GPS monitor (WiSPI, GPSports, Australia), worn in a manufacturer produced harness mounted between the shoulder blades. Heart rate data were received through the GPS device from an elastic chest strap (Polar, Fi). The GPS units used in this study were a small (91 × 45 × 21 mm^3) water resistant monitor with an in-built tri-axial accelerometer (WiSPI, GPSports, Australia). All devices recorded continuously for the duration of that shift and were removed by the researchers as the participant returned to the pre-shift briefing area at the completion of their shift.

During all shifts, participants wore full personal protective equipment, consisting of a two piece proban treated pant and jacket ensemble (Stewart and Heaton, Australia), FirePro fire resistant gloves (Allglove Industries, Australia), treated leather work boots (Taipan, Australia) and a wildfire fighting hard hat (Protector Alsafe, Australia). Participants carried and may have used fire safety goggles (UVEX, Germany) and disposable breathing masks (Dräger, Germany). Clothing worn under personal protective equipment was not recorded but generally comprised light, cotton t-shirt and athletic shorts. The net weight of firefighting equipment was approximately 5 kg. Ethical and technical approval for the study was obtained from the Deakin University Human Research Ethics Committee and the Australasian Fire and Emergency Service Authorities Council.

Throughout their shift, each firefighter was followed by a researcher and a fire-service provided safety advisor. The researcher used a handheld, digital video camera (JVC model GZ-MG330 and GZ-MG555 Everio® HDD camcorders) to capture footage of the firefighter's work tasks and movements. Researchers did not film firefighters during rest periods (i.e. lunch, personal breaks) or during vehicle transit. The commencement and cessation of video recording were manually logged by each researcher.

Data analysis

At the conclusion of each shift, logged GPS co-ordinates were downloaded from the devices and converted into distance and velocity information using Team AMS software (GPSports, Australia). Heart rate and velocity data were downloaded at one-second epochs to an Excel spreadsheet (Microsoft, Redmond, WA). Digital video was captured by Dartfish TeamPro® (Fribourg, Switzerland) and the types of tasks analysed were identified using a custom made rural fire fighting specific tagging profile. The custom made tagging profile was based on job task analysis for Australian rural firefighters during wildfire suppression [2]. The tagging profile was used to quantify the frequency and duration for each discrete task performed by the firefighters. The footage was time-synchronised with heart rate and velocity data to isolate the intensity (heart rate and velocity) of each task. This was performed using the functionality of the Dartfish software, which allows the input of other measures. Task velocity is expressed in $m \cdot s^{-1}$ and heart rate in both absolute units ($beats \cdot min^{-1}$) and relate to age-predicted maximum (%HRmax) using the predictive formula, HRmax=207 – (0.7 × Age) [29].

Statistical analysis

Following confirmation of a normal distribution (using *Shaprio-Wilk* tests), independent sample t-tests were used to compare the personal demographics of the male and female participants. Statistical significance was set a P<0.05. All tasks (32 in total) were ranked in terms of frequency, intensity and time, and the top 10 tasks for each measure are presented. The full list of 32 tasks is not presented. Instead, Tables 1-4 present the ten most frequent, most intense (based on mean heart rate), fastest, and longest tasks performed during the wildfire suppression shifts. At present there is no consensus on the method researchers should use for distilling tasks into a short-list of 'critical' tasks [18,30]. In the current study, tasks that appear on two or more of these lists were presented (Table 5) to capture the most frequent, intense and longest tasks performed by firefighters during wildfires. All data are presented as mean ± standard deviation unless otherwise stated.

Results

Participants

There was no difference in age between male and female participants (P=0.780). The mean age of the sample was 38 ± 14 yr. The male participants were 1.8 ± 0.1 m tall and weighed 94.9 ± 17.8 kg. The female participants were 1.6 ± 0.1 cm and weighed 81.0 ± 11.8 kg. When matched for age, the male participants were 0.2 ± 0.1 m taller (P<0.01) and 13.9 ± 23.2 kg heavier (P=0.02) than the female participants. The mean body max index for the sample was 30.5 ± 4.9 kg·m^{-2}, with no differences (P=0.629) between the sexes. The mean length of brigade membership was 9 ± 8 yr, with no differences between the sexes (P=0.470).

Fireground tasks

Across the four fireground 'shifts', the firefighters performed 32 distinct fireground tasks. Nineteen tasks could be classified as hose work, five as handtool (primarily rakehoe), and eight as miscellaneous. Per shift, the task frequency ranged from once (raking fireline in teams, carrying a quick fill pump) to 103 times (lateral repositioning of a 38-mm charged firehose). The task intensity, as measured by mean heart rate ranged between 97 ± 16 beats·min^{-1} (55.7 ± 8.7%HRmax) and 157 ± 15 beats·min^{-1} (86.2 ± 10.8%HRmax). The tasks were performed a speeds that ranged from 0.12 ± 0.08 m·s^{-1} (manual hose retraction of 38-mm charged fivehose) to 0.79 ± 0.40 m·s^{-1} (carrying a 38-mm coiled hose). The tasks lasted between 4 ± 2 s (rolling ('bowling') out 38-mm firehose) and 461 ± 387 s (raking fireline in teams).

Task frequency

The ten most frequently performed tasks are presented in Table 1. Per shift, the task frequency ranged from 29 (mounting and dismounting the fire truck) to 103 (lateral repositioning of a 38-mm charged firehose). Six of the most frequent tasks were classified as hose work, one as handtool work, and three as miscellaneous tasks.

Task	**Frequency**	**Mean HR (beats·min-1) (%HR max)**	**Peak HR (beats·min^{-1}) (%HR max)**	**Speed (m·s^{-1})**	**Duration (s)**	**Type (Hose, Rake, Misc)**
Lateral repositioning 38-mm hose	103	127 ± 23 (71.5 ±12.6)	130 ± 23 (73.2 ± 15.5)	0.40 ± 0.29	17 ± 14	Hose
Targeted walk	95	117 ± 25 (64.8 ±12.7)	121 ± 25 (66.9 ± 12.8)	0.76 ± 0.51	23 ± 29	Misc
Support 38-mm hose operator	66	123 ± 26 (68.9 ±13.2)	128 ± 26 (72.1 ± 13.4)	0.28 ± 0.35	50 ± 58	Hose
Lateral repositioning 25-mm hose	61	110 ± 26 (62.1 ±12.1)	114 ± 26 (64.1 ± 12.0)	0.39 ± 0.31	17 ± 16	Hose
Support 25-mm hose operator	57	107 ± 25 (61.1 ±12.0)	113 ± 26 (64.2 ± 12.0)	0.20 ± 0.18	46 ± 58	Hose
Blacking out work using 38-mm hose	41	126 ± 24 (71.9 ±15.3)	131 ± 24 (75.0 ± 15.0)	0.26 ± 0.19	76 ± 70	Hose
Petrol & Carry hand tool	41	127 ± 28 (68.3 ±14.2)	133 ± 28 (71.5 ± 14.6)	0.39 ± 0.26	47 ± 59	Rake
Operating 38-mm hose	41	124 ± 19 (69.8 ±10.6)	129 ± 20 (72.4 ± 10.8)	0.34 ± 0.37	40 ± 58	Hose
Pump operation	34	111 ± 20 (61.6 ±11.2)	116 ± 20 (64.0 ± 11.0)	0.32 ± 0.62	29 ± 35	Misc
Mount/dismount	29	113 ± 25	115 ± 24	0.29 ± 0.28	5 ± 4	Misc

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		(61.8 ±12.4)	(62.8 ± 12.2)			

Table 1: Ten most frequent tasks performed per shift during wildfire suppression. All data are means ± SD, HR: Heart Rate; min: Minutes; %HRmax: Percentage of Age-predicted Heart Rate Maximum (14); $m \cdot s^{-1}$: Metres per Second; SD; Standard Deviation; Misc: Miscellaneous Task; mm: Millimetres.

Task intensity

The ten tasks with the highest mean relative heart rate (i.e., %HRmax) are presented in Table 2. The mean heart rates ranged from 69.4 ± 15.1%HRmax (raking during blacking out) to 86.2 ± 10.8%HRmax (raking fireline in teams). Eight tasks were classified as hose work, whilst the remaining two were considered handtool tasks.

The ten fastest tasks are presented in Table 3. The mean speed ranged from 0.40 ± 0.26 $m \cdot s^{-1}$ (tightly coiling a 38-mm fire hose) to 0.79 ± 0.40 $m \cdot s^{-1}$ (carrying a 38-mm coiled hose). Eight tasks were classified as hose work, whilst the remaining two were considered miscellaneous tasks.

Task	Frequency	Mean HR (beats·min^{-1}) (%HR max)	Peak HR (beats·min^{-1}) (%HR max)	Speed (m·s^{-1})	Duration (s)	Type (Hose, Rake, Misc)
Team line building	1	157 ± 15 (86.2 ± 10.8)	168 ± 10 (92.2 ± 7.7)	0.14 ± 0.08	461 ± 387	Rake
Carry coiled 38-mm hose	6	156 ± 29 (83.4 ± 13.7)	161 ± 28 (86.0 ± 13.4)	0.79 ± 0.40	49 ± 60	Hose
Making up 38-mm hose on bite	5	155 ± 24 (82.1 ± 12.9)	164 ± 25 (86.8 ± 13.2)	0.40 ± 0.26	62 ± 47	Hose
Manual 38-mm hose retraction	3	141 ± 29 (78.5 ± 16)	145 ± 29 (80.7 ± 15.6)	0.12 ± 0.08	45 ± 35	Hose
Advance uncharged 38-mm hose	3	133 ± 16 (72.3 ± 6.6)	137 ± 17 (74.5 ± 6.8)	0.46 ± 0.27	21 ± 12	Hose
Blacking out work using 38-mm hose	41	126 ± 24 (71.9 ± 15.3)	131 ± 24 (75.0 ± 15.0)	0.26 ± 0.19	76 ± 70	Hose
Lateral repositioning 38-mm hose	103	127 ± 23 (71.5 ± 12.6)	130 ± 23 (73.2 ± 15.5)	0.40 ± 0.29	17 ± 14	Hose
Operating 38-mm hose	41	124 ± 19 (69.8 ± 10.6)	129 ± 20 (72.4 ± 10.8)	0.34 ± 0.37	40 ± 58	Hose
‘Bowling’ out 38-mm hose	2	130 ± 36 (69.8 ± 18.8)	130 ± 36 (70.2 ± 18.7)	0.53 ± 0.54	4 ± 2	Hose
Rake hoe during blacking out	24	130 ± 29 (69.4 ± 15.1)	134 ± 31 (71.6 ± 15.9)	0.22 ± 0.11	25 ± 25	Rake

Table 2: Ten most intense tasks (as ranked using mean, relative heart rate) performed per shift during wildfire suppression. All data are means ± SD, HR: Heart Rate; min: Minutes; %HRmax: Percentage of Age-predicted Heart Rate Maximum (14) ; $m \cdot s^{-1}$: Metres per Second; SD: Standard Deviation; Misc: Miscellaneous Task; mm: Millimetres.

Task	Frequency	Mean HR (beats·min^{-1}) (%HR max)	Peak HR (beats·min^{-1}) (%HR max)	Speed (m·s^{-1})	Duration (s)	Type (Hose, Rake, Misc)
Carry coiled 38-mm hose	6	156 ± 29 (83.4 ± 13.7)	161 ± 28 (86.0 ± 13.4)	0.79 ± 0.40	49 ± 60	Hose

Support crew on fireline	5	101 ± 18 (55.0 ± 9.9)	112 ± 21 (60.8 ± 11.6)	0.78 ± 0.71	79 ± 51	Rake
Targeted walk	95	117 ± 25 (64.8 ± 12.7)	121 ± 25 (66.9 ± 12.8)	0.76 ± 0.51	23 ± 29	Misc
Move uncharged 38-mm hose onto fire break	3	120 ± 15 (65.9 ± 8.7)	126 ± 16 (69.2 ± 8.7)	0.57 ± 0.43	20 ± 15	Hose
Advance 38-mm charged hose	14	115 ± 23 (66.7 ± 13.4)	118 ± 23 (68.3 ± 13.3)	0.54 ± 0.48	17 ± 11	Hose
Full repositioning of 25-mm hose	7	106 ± 19 (59.1 ± 10.3)	115 ± 19 (64.0 ± 9.7)	0.54 ± 0.28	78 ± 42	Hose
'Bowling' out 38-mm hose	2	130 ± 36 (69.8 ± 18.8)	130 ± 36 (70.2 ± 18.7)	0.53 ± 0.54	4 ± 2	Hose
Advance 25-mm charged hose	14	104 ± 19 (59.5 ± 10.2)	109 ± 19 (61.8 ± 9.6)	0.49 ± 0.30	18 ± 10	Hose
Advance uncharged 38-mm hose	3	133 ± 16 (72.3 ± 6.6)	137 ± 17 (74.5 ± 6.8)	0.46 ± 0.27	21 ± 12	Hose
Making up 38-mm hose on bite	5	155 ± 24 (82.1 ± 12.9)	164 ± 25 (86.8 ± 13.2)	0.40 ± 0.26	62 ± 47	Hose

Table 3: Ten fastest tasks performed per shift during wildfire suppression. All data are means ± SD, HR: Heart Rate; min: Minutes; %HRmax: Percentage of Age-predicted Heart Rate Maximum (14); m·s-1: Metres per Second; SD: Standard Deviation; Misc: Miscellaneous Task; mm: Millimetres.

Task duration

The ten longest tasks are presented in Table 4. The tasks ranged in length from 54 ± 67 s (manually retracting a 25-mm firehose) to 461 ± 387 s (raking fireline in teams). Six tasks were classified as hose work, two as handtool work, and two as miscellaneous tasks.

Task	Frequency	Mean HR (beats·min^{-1}) (%HR max)	Peak HR (beats·min^{-1}) (%HR max)	Speed (m·s^{-1})	Duration (s)	Type (Hose, Rake, Misc)
Team line building	1	157 ± 15 (86.2 ± 10.8)	168 ± 10 (92.2 ± 7.7)	0.14 ± 0.08	461 ± 387	Rake
Blacking out work using 25-mm hose	20	107 ± 18 (59.0 ± 10.7)	116 ± 20 (64.2 ± 10.6)	0.18 ± 0.15	130 ± 138	Hose
Draughting	6	97 ± 16 (55.7 ± 8.5)	108 ± 20 (62.4 ± 10.0)	0.18 ± 0.13	119 ± 112	Misc
Support crew on fireline	5	101 ± 18 (55.0 ± 9.9)	112 ± 21 (60.8 ± 11.6)	0.78 ± 0.71	79 ± 51	Rake
Full repositioning of 25-mm hose	7	106 ± 19 (59.1 ± 10.3)	115 ± 19 (64.0 ± 9.7)	0.54 ± 0.28	78 ± 42	Hose
Full repositioning of 38-mm hose	7	113 ± 27 (65.6 ± 18.1)	119 ± 28 (69.4 ± 18.5)	0.40 ± 0.22	76 ± 64	Hose
Blacking out work using 38-mm hose	41	126 ± 24 (71.9 ± 15.3)	131 ± 24 (75.0 ± 15.0)	0.26 ± 0.19	76 ± 70	Hose

Quickfill pump set up	5	107 ± 13 (58.5 ± 8.0)	115 ± 13 (62.3 ± 8.2)	0.24 ± 0.13	70 ± 73	Misc
Making up 38-mm hose on bite	5	155 ± 24 (82.1 ± 12.9)	164 ± 25 (86.8 ± 13.2)	0.40 ± 0.26	62 ± 47	Hose
Manual 25-mm hose retraction	7	126 ± 27 (68.3 ± 14.5)	133 ± 28 (72.0 ± 15.0)	0.15 ± 0.13	54 ± 67	Hose

Table 4: Ten longest tasks performed per shift during wildfire suppression. All data are means ± SD, HR: Heart Rate; min: Minutes; %HRmax: Percentage of Age-predicted Heart Rate Maximum (14) ; $m{\cdot}s^{-1}$: Metres per Second; SD: Standard Deviation; Misc: Miscellaneous Task; mm: Millimetres.

Frequency, intensity, time (duration), and type

Table 5 presents a composite list of tasks that were ranked in the top 10 for at least two of frequency, intensity (mean relative heart rate) and duration. The 10 fastest tasks (Table 3) were not included in the composite list as to not bias the scaling towards two measures of intensity (i.e., heart rate and velocity). Blacking out (i.e., extinguishing smouldering fuel sources) using a 38-mm hose was ranked in the top 10 tasks for frequency, intensity, and duration. The remaining four tasks were ranked in the top 10 for two of frequency, intensity, and duration. This composite list comprises four hose work tasks and one handtool task.

Task	Frequency	Mean HR (beats·min^{-1}) (%HR max)	Peak HR (beats·min^{-1}) (%HR max)	Speed (m·s^{-1})	Duration (s)	Type (Hose, Rake, Misc)
Blacking out work using 38-mm hose	41	126 ± 24 (71.9 ± 15.3)	131 ± 24 (75.0 ± 15.0)	0.26 ± 0.19	76 ± 70	Hose
Lateral repositioning 38-mm hose	103	127 ± 23 (71.5 ± 12.6)	130 ± 23 (73.2 ± 15.5)	0.40 ± 0.29	17 ± 14	Hose
Operating 38-mm hose	41	124 ± 19 (69.8 ± 10.6)	129 ± 20 (72.4 ± 10.8)	0.34 ± 0.37	40 ± 58	Hose
Making up 38-mm hose on bite	5	155 ± 24 (82.1 ± 12.9)	164 ± 25 (86.8 ± 13.2)	0.40 ± 0.26	62 ± 47	Hose
Team line building	1	157 ± 15 (86.2 ± 10.8)	168 ± 10 (92.2 ± 7.7)	0.14 ± 0.08	461 ± 387	Rake

Table 5: Tasks that were ranked in the top ten for two or more of frequency, intensity (mean relative heart rate), and duration during wildfire suppression. All data are means ± SD, HR: Heart Rate; min: Minutes; %HRmax: Percentage of Age-predicted Heart Rate Maximum (14); $m{\cdot}s^{-1}$: Metres per Second; SD: Standard Deviation; Misc: Miscellaneous Task; mm: Millimetres.

Discussion

The major aims of the current study were to quantify the frequency, intensity, duration, and type of tasks performed by Australian rural fire crews when suppressing wildfires. Across four shifts, firefighters performed 32 discrete tasks. Per shift, their task frequency ranged from one to 103 repetitions. The tasks were associated with mean and peak heart rates that spanned the light to hard exercise intensity classifications, as specified by the American College of Sports Medicine (ACSM). All tasks were performed at speeds below 1 $m{\cdot}s^{-1}$. Individual tasks lasted between four seconds and eight minutes. Nineteen tasks could be classified as hose-related, five as rakehoe, and eight as miscellaneous. Only five tasks (four hose, one rakehoe) were ranked in the top 10 on two (or more) of the frequency, intensity and duration scales.

To the authors' knowledge, no other study has quantified the frequency with which firefighting tasks are performed on shift. Comparisons to our previously reported experienced firefighters' subjective estimations of task frequency for seven physically demanding wildfire suppression tasks [2] are also problematic. In the Phillips et al. [2] study, task frequency was estimated per four-month Australian wildfire season making it difficult to precisely compare to the 'per shift' observations reported in the current study. However, a comparison of the relative 'rankings' shows that both subject matter experts and the current observations rank fire hose lateral repositioning as the most frequent task, followed by full repositioning and handtool work during mopping up (i.e., post-fire clean up). Solo and team base handtool work were amongst the least frequent tasks in both studies. The most frequent tasks observed in the current study may also parallel frequent tasks observed during urban firefighting [8]. Bos et al. [20] reported that urban Dutch firefighters identified a range of tasks as most frequent across a 24-hour shift, but did not report the number of repetitions performed for each task. Of the 'most frequent' activities (i.e., actions within global tasks) listed by Bos et al. [8] pulling and dragging hoses parallels the lateral repositioning of 38-mm and 25-mm charged fire hoses (Table 1) identified as the first and fourth most frequent wildfire suppression tasks (Table 1). In the current study also reported that operating a 38-mm charged fire hose (to deliver water or other suppressant), and supporting firefighters to perform this task (or operate a 25-mm firehose) were amongst the most frequent tasks (Table 1). These tasks could correspond (or at least contribute) to the 'extinguishing' task set identified as 'most frequent' by Bos et al. [8]. Possible task similarities between Dutch urban and Australian rural firefighters lends weight to our earlier conclusions regarding the overlap in work practices between structural firefighting worldwide and wildfire suppression by Australian rural firefighters [2].

The peak and mean heart rates (relative to age-predicted maximum) reported in the current study were, generally speaking, lower than those recorded in simulations of wildfire [26], urban [5], naval [3], and forestry [28] firefighting tasks. The lower heart rates observed in the current study can be explained, at least in part, by the shorter task durations and slower task speeds observed, and in some cases, lighter equipment used in the current study compared to previous research [3-5,31,32]. Differences between observed and simulated work rates are not limited to our work. For example, Bos et al. [8] showed that the mean heart rate per urban firefighting task was much lower during a 24-hour shift than had been reported during simulations of urban firefighting tasks [5]. The higher heart rates observed in simulation may be related to either the longer task duration, which could be a function of researchers seeking to establish steady-state cardiovascular responses to a particular task [3]. Alternatively, participants, despite instructions to perform simulated tasks 'as they would on the job', may work at a higher speed than they do in the field [9]. This observation may reflect a form of 'reactivity' where participants increase their physical activity when they know they are being monitored or can view their pedometer [32]. It is also possible that emergency service workers lower their task speed and therefore heart rate to pace their efforts across a whole shift. This hypothesis, though raised previously by Budd and colleagues [9] is yet to be directly tested, though recent observations of Spanish wildland firefighters [33] do show a lowering of mean heart rate with longer shifts. Future simulations of emergency services tasks and work may, accordingly, require multiple task repetitions to adequately represent the work demands faced 'on the job'.

The task durations observed in the current study are also considerably shorter than those proposed by experienced Australian rural firefighters during a subjective job task analysis on wildfire suppression [2]. The comparison, notwithstanding small differences in tasks between Australian rural fire authority jurisdictions, could question the accuracy and hence value of subjective ratings of task duration from subject-matter experts. Relative time spent on task (analogous to task duration) ratings has been shown to have considerably higher variability than measures of relative importance [18]. It is possible however, that the high variability observed for task duration reflects genuine differences in the experiences of different subject-matter experts rather than systemic context-related error in the task analysis [16]. Indeed, the apparent differences in task duration between subjective job task analyses and the current observations of wildfire suppression may indicate that the full range of task durations could not be observed across the four suppression shifts. Researchers and emergency service agencies must, accordingly, weigh the benefits of more accurate job task analyses through direct observation [34] against the possibility that key task parameters may not be observed during the observation 'window' [34,35].

The prevalence of hose and handtool work (Tables 1-5) strengthens our earlier conclusions that the firefighting tactics performed by Australian rural fire crews were a hybrid of urban [5] and North American forestry [27] and Australian land management [36] firefighting approaches. In these jurisdictions, seasonal and sometimes incumbent personnel are required to pass physical employment standards [37] before deployment to the fireground. At present Australian rural authority firefighters do not have a purpose-built physical selection test. In an effort to identify the representative tasks that could feature in such a test, we isolated the tasks that were ranked in the top 10 for two (or more) of frequency, intensity (heart rate) and duration (Table 5). Identifying tasks that are simultaneously frequent and demanding (as measured here by mean heart rate) is analogous to the critical task paradigm presented by Taylor and Groeller [35]. The only difference is Taylor and Groeller [35] incorporated task importance into their product of task frequency and intensity (or cumulative stress). At present there is no consensus on the method researchers should use for distilling tasks into a short-list of 'critical' tasks, but the reader is referred to recent reviews [18,30] for a more comprehensive discussion. When combined, however, with our previous work classifying the operational importance of physically demanding tasks [2] the following tasks are added to those presented in Table 5; advancing a 38-mm diameter firehose 'charged' with water, full repositioning of a 38-mm charged fire hose, rapid handtool work during spot fire containment, solo handtool work, and handtool work during blacking out (i.e., post-fire clean up). Lateral reposition of a 38-mm charged firehose, and handtool work during team fireline building feature in both studies. These two tasks, together with a selection of those listed above [2] and in Table 5 should reasonably form the basis for any physical selection test or representative work task circuit for Australian rural fire authority personnel fighting wildfires.

The current study represents a significant step forward in the analyses of task demands of physically demanding occupations. The combination of video footage, heart rate and GPS data allows in situ analysis of task frequency and duration during actual working conditions. However, it should be acknowledged that the current data is based on a relatively small sample of firefighters (n=28) working across four fire days. More research, across a range of environments is required to verify the current findings beyond the local context. Indeed, the current sample size does not have the statistical power to comprehensively investigate the range of moderating factors (see [38] for further discussion) that could influence firefighters' work behaviour and physiological responses. The modest sample reflects, in part, the time and labour intensive nature of the data collection methods used in the current study. Here, each firefighter was filmed by an individual research assistant and their footage synchronised with high resolution heart rate and GPS data. Individual task taxonomy, extraction and analyses were also exhaustive processes. The current approach may, therefore, be best suited for detailed analyses of local firefighting tactics and should be synthesized with the results from larger scale remote monitoring studies (e.g., [10,12,13]) to garner a broad spectrum view of the tasks demands faced by wildland firefighters across their suppression shifts.

The current study analysed the type, intensity, frequency and duration of tasks performed during wildfire suppression shifts. The observed fireground tasks were, generally speaking, slower, performed at lower speeds, and elicited lower heart rate responses than simulated tasks in wildfire, structural, naval, or forestry contexts. The tasks were also shorter than previous subjective job task analysis findings, supporting a recent review [18] in this area. The current results, albeit drawing upon a modest sample, indicate that single repetition task simulations may not accurately capture work demands. These results, if replicated across other jurisdictions could significantly alter the process used to design job-specific fitness testing and training regimes. From the 32 tasks observed, only five tasks were found to be simultaneously frequent, long and intense (or ranked in the top 10 tasks for two of these three indices). They were team line building, lateral repositioning of a 38-mm firehose, using a 38-mm firehose during blacking out, operating a 38-mm firehose, and tightly coiling a 38-mm fire hose. These tasks are likely to form the basis for any future job-specific testing or training for Australian rural firefighters suppressing wildfires.

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