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Article

Firefighters' Physical Activity across Multiple Shifts of Planned Burn Work

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Abstract: Little is currently known about the physical activity patterns of workers in physically demanding populations. The aims of this study were to (a) quantify firefighters' physical activity and sedentary time within (2-h periods) and across planned burn shifts; and (b) examine whether firefighters' activity levels during one shift or 2-h period was associated with their activity levels in the following shift or 2-h period. Thirty-four salaried firefighters (26 men, 8 women) wore an Actical accelerometer for 28 consecutive days. Time spent sedentary (SED) and in light- (LPA), moderate- (MPA) and vigorous-intensity physical activity (VPA) were derived using validated cut-points. Multilevel analyses (shift, participant) were conducted using generalised linear latent and mixed models. Firefighters spent the majority of a planned burn shift (average length 10.4 h) or 2-h period engaged in LPA (69% and 70%, respectively). No significant associations were observed between SED and physical activity levels between consecutive planned burned shifts or 2-h periods. The physical activity that a firefighter engaged in during one shift (or 2-h period) did not subsequently affect their physical activity levels in the subsequent shift (or 2-h period). Further research is needed to establish how workers in physically demanding populations are able to sustain their activity levels over long periods of time.

Keywords: firefighting; actigraphy; prescribed burning; hazard reduction burning; workplace; environment

1. Introduction

Firefighting is a physically demanding occupation that includes strenuous duties performed over long shifts (10–12 h), often across consecutive days [1,2]. Annually, Australian firefighters are routinely deployed to undertake planned burn operations [2]. Planned burns are an important preventative strategy whereby a fire is purposely lit to reduce the size, number, severity, and intensity of future wildfires [3,4]. In 2015, 324 planned burns (covering 1964 hectares and 701 km) were conducted throughout Australia [5]. Due to the ever-increasing threat of wildfire, it is predicted that the number and scale of planned burns will continue to rise [6]. However, despite being a regular operational duty, little is currently known about firefighters' physical activity levels during planned burn operations.

The majority of research examining physical activity levels of firefighters on-shift largely focuses on emergency scenarios such as wildfires [7,8], with some studies also examining experimentally lit burns [9,10]. These studies have typically quantified physical activity levels either within-shift (i.e., 2-h time periods) or for the whole duration of the shift, describing the total volume of activity that firefighters engage in or comparing differences in activity levels between 2-h periods or shifts [7–10].

Regardless of the approach, mixed findings have been reported in the literature to date. For example, several studies have reported no differences in activity levels between shifts or between 2-h periods, suggesting that firefighters pace themselves to ensure operations are completed [7,11,12]. In contrast, others have reported that physical activity levels are higher during the first wildfire shift (or 2-h period within-shift) and decrease over time [13,14]. Whilst these studies provide insights into how physical activity levels may change within- or between-shifts as a result of situational contexts (e.g., intensity of the fire), the between-person or between-group (e.g., different hydration status groups) nature of the analyses do not account for within-person effects across a shift or between shifts. That is, does the physical activity that a firefighter engages in during one shift (or 2-h period) subsequently affect their physical activity levels in the subsequent shift (or 2-h period)? It has been hypothesised that individuals have an internal 'set-point' (activitystat) that controls their physical activity over time, which is similar to other homeostatic processes within the body [15]. This hypothesis suggests that increases in activity during a given time period result in subsequent decreases in another time point (i.e., activity compensation) to maintain this overall activity set-point [15]. Given the typical nature of planned burn operations (i.e., long shifts over consecutive days), this may have significant implications for firefighters undertaking physical work. As such, there is a need to examine whether high levels of activity during one time period results in decreases in physical activity in the next time period. Understanding the temporal nature of firefighters' physical activity will help to identify, for example, whether operational duties may be compromised and if there is a need for strategies to protect the safety of firefighters during planned burn operations (e.g., regular rest breaks, more firefighters in rotation, etc.).

Consequently, the aims of the study were twofold. Firstly, this study quantified firefighters' physical activity levels and sedentary time within (2-h periods) and across shifts during planned burn operations. Secondly, this study examined whether firefighters' physical activity and sedentary time during one shift or 2-h period was associated with their activity levels in the following shift or 2-h period.

2. Materials and Methods

2.1. Recruitment and Participants

Participants were recruited through an advertisement circulated to the Australasian Fire and Emergency Services Authority Council communications officers. Approximately 250 accredited firefighters contacted the research team directly, and 53 salaried firefighters provided written informed consent to participate in the study. Of these, 38 firefighters (29 male, 9 female) completed all aspects of data collection (i.e., work diary, accelerometry) over a 28-day period in 2013 or 2014. Self-reported health data, obtained from a General Health Questionnaire, and firefighting experience were collected prior to the study commencing. Participants were located throughout Australia. Height and weight measurements (used to calculate their body mass index (BMI)) were also self-reported. No relevant diagnosed medical disorders were reported by participants. Data were also collected on participants' sleep between consecutive shifts, which have been published elsewhere [16]. Ethical approval was obtained from the University's Human Research Ethics Committee (2012-300; approved 15 November 2012).

2.2. Measures

Firefighters completed a daily work diary over the 28-day data collection period. Data collected included shift start and end times (used to identify shift length), travel time, the burn location, a brief overview of their shift work (e.g., used a rakehoe, extinguished debris, etc.), and information regarding their sleep behaviour between-shifts. This diary has previously been used in wildfire research [8].

Participants wore an accelerometer (Phillips Actical MiniMitter/Respironics, Bend, OR, USA) on their non-dominant wrist for 28 consecutive days. The Actical (28 × 27 × 10 mm, 17 g) monitor

uses a piezoelectric omnidirectional accelerometer, which is sensitive to movements in all planes in the range of 0.5–3.0 Hz, and measures the frequency, intensity, and duration of human movement [17]. The Actical has acceptable validity (0.62) and reliability (0.81–0.99) for objectively measuring sedentary time (SED), physical activity intensities, and sleep in 1-min epochs [18,19]. Firefighters were instructed to wear the monitor for the whole day (including sleep) and to only remove the Actical during periods when immersion in water was likely (e.g., whilst showering).

2.3. Data Management

Accelerometer data were downloaded using Actical software (Phillips Actical MiniMitter, software v.3.10, Respironics, Bend, OR, USA). This software uses validated location-specific algorithms that determine time spent (min) in light- (LPA; ≥ 1.5 –2.99 metabolic equivalents (METs)), moderate- (MPA; ≥ 3.0 –5.99 METs), and vigorous-intensity physical activity (VPA ≥ 6 METs [19]). Average activity counts for three consecutive minutes of less than 50 counts·min⁻¹ were classified as sedentary time (SED; Respironics, personal communication). Non-wear time was defined as periods of at least 60 min of consecutive zeros, which is the most commonly used non-wear definition in adults [17]. Activity counts less than 40 counts per epoch for at least 10 min were used to identify sleep periods [20]. All downloaded data were subsequently reduced using a customized Microsoft Excel macro to determine the total and percentage of time spent sedentary and in different physical activity intensities for each shift and within-shift period (2-h period). As collected data are date and time stamped, it was possible to extract SED and physical activity intensities for each planned burn shift using the daily diary completed by participants. For a shift or 2-h period to be included in the analyses, firefighters were required to have worn the Actical monitor for at least 50% of a planned burn shift or 2-h period, in accordance with previous physical activity research [8,21,22]. Self-reported shift start and end times were used to determine each planned burn shift for the between-shift analysis. For the within-shift analysis, shifts were divided into 2-h periods in accordance with previous firefighting research [11,12].

2.4. Statistical Analyses

All data were analysed using Stata v14 (StataCorp, College Station, TX, USA). Descriptive statistics (mean \pm standard deviation (SD)) were initially calculated for all measured variables. Descriptive Actical data were initially checked for normality using histograms to plot the distribution. Data approximated to a normal distribution for the physical activity variables. The average proportion of time spent in SED, LPA, MPA, and VPA were calculated for each firefighter's planned burn shift and for each 2-h period. Due to the range of planned burn shift lengths (5–17 h), exploratory analyses were conducted to examine the number of firefighters contributing data to each 2-h period. As the number of firefighters contributing data decreased from 31 to 11 after shift lengths of 14 h, the descriptive examination of activity patterns within-shifts was capped at 14 h (i.e., seven 2-h periods included). However, all 2-h periods were included in the main analysis described below.

To account for the clustered nature of the collected data (i.e., multiple time points collected within the same firefighter), the main analyses consisted of multilevel models that were performed using the generalised linear latent and mixed models (GLLAMM; v.2.3.20) procedure [23]. GLLAMMs are a class of multilevel latent variable models [23]. Multilevel models are the most appropriate technique for analysing hierarchical, correlated data that are not independent of each other and violate the assumption of independent observations for traditional regression analyses [24]. Multilevel models allow a more in depth analysis into the within-participant factors [25]. As multilevel models are robust against missing data points and can estimate effects using incomplete data sets, all valid shift and 2-h period data collected were included in the analyses [24].

The main analyses consisted of estimating associations between temporally adjacent values between the outcome variables. The physical activity and sedentary time outcomes obtained for each shift or 2-h period were used in the analyses, as GLLAMMs are able to satisfy normality assumptions without the need for transformations [26]. The between-shift analyses examined whether the amount

of time (min) a firefighter spent in a specified physical activity level (e.g., MPA) or SED during any given shift (shift s in the model) was associated with their physical activity (e.g., MPA) or SED during the previous shift (shift $s - 1$ in the model [27]). All data collected from temporally adjacent shift pairs were used (e.g., shift 3 (s) compared with shift 2 ($s - 1$), shift 2 (s) compared with shift 1 ($s - 1$), etc.). This approach takes into account that an active shift may be followed by a low active shift (e.g., due to the changing nature of the fire) or vice versa. The within-shift analyses examined whether the amount of time a firefighter spent in a specified physical activity level or SED during any given 2-h period (period p in the model) was associated with their physical activity or SED during the previous 2-h period (period $p - 1$ in the model). All data collected from temporally adjacent 2-h periods were used (e.g., period 3 (p) compared with period 2 ($p - 1$), period 2 (p) compared with period 1 ($p - 1$), etc. [27]). For both sets of analyses, the number of shift or period pairs included in the final analyses depended on the number of consecutive shifts attended or shift length. In all models, the random structure considered random intercepts at the participant level. This meant that the observation predicted by the intercept for each firefighter was allowed to vary. A two-level model was used for the between-shift analyses, namely shift (level 1) and firefighter (level 2). A three-level model was used for the within-shift analyses, namely shift period (level 1), shift (level 2), and firefighter (shift 3). All models were adjusted for age, sex, BMI, firefighting experience, and wear time, which were identified as covariates a priori. Sleep duration was included as an additional covariate for the between-shifts analyses. A total of 166 shift-pairs were included in the between-shifts analyses and 1172 2-h period-pairs were included in the within-shifts analyses. Final parameter estimates are reported as b coefficient \pm 95% confidence interval (CI). Statistical significance was set at $p < 0.05$.

3. Results

3.1. Descriptive Characteristics

Data were collected from 38 participants (29 men and 9 women). Two monitors were water damaged resulting in irretrievable data loss. Furthermore, one participant only attended training activities, and one participant did not wear their monitor during planned burn shifts; thus, both were also excluded from the analyses. This resulted in a final sample of 34 participants (26 men and 8 women aged 20–60 years). Demographic data are presented in Table 1.

Table 1. Participant and study characteristics.

	Mean \pm SD	Range
A. Participant characteristics		
Age (year)	37.8 \pm 10.9	20–60
Height (m)	1.8 \pm 0.1	1.6–2.0
Weight (kg)	82.2 \pm 13.7	49–105
BMI ($\text{kg}\cdot\text{m}^2$) ^a	26.3 \pm 3.4	18–36
Firefighting experience (years)	8.0 \pm 8.1	1–32
Sleep duration (h)	6.8 \pm 1.1	4–11
B. Whole shift physical activity		
SED (min)	39.8 \pm 32.2	0.8–183
LPA (min)	430.1 \pm 111.6	160–623
MPA (min)	152.6 \pm 67.2	31–326
VPA (min)	0.2 \pm 0.5	0–2.4
Wear time (min)	622.6 \pm 123.2	238–785

Note: $n = 34$; m: meters; kg: kilograms; BMI: body mass index; $\text{kg}\cdot\text{m}^{-2}$: kilograms per metre squared; h: hours; SED: sedentary time; min: minutes; LPA: light-intensity physical activity; MPA: moderate-intensity physical activity; VPA: vigorous-intensity physical activity. ^a Calculated from self-reported height and weight measurements in the General Health Questionnaire.

3.2. Average Physical Activity Levels and Sedentary Time Within- and Between-Shifts

The average shift length of a planned burn operation was 10.4 ± 2.1 h. The proportions of time spent in SED and each level of physical activity intensity during a whole shift and within each 2-h period are shown in Figures 1 and 2, respectively. On average, firefighters engaged in LPA for the majority of a shift (69%) and across each 2-h period (70%).

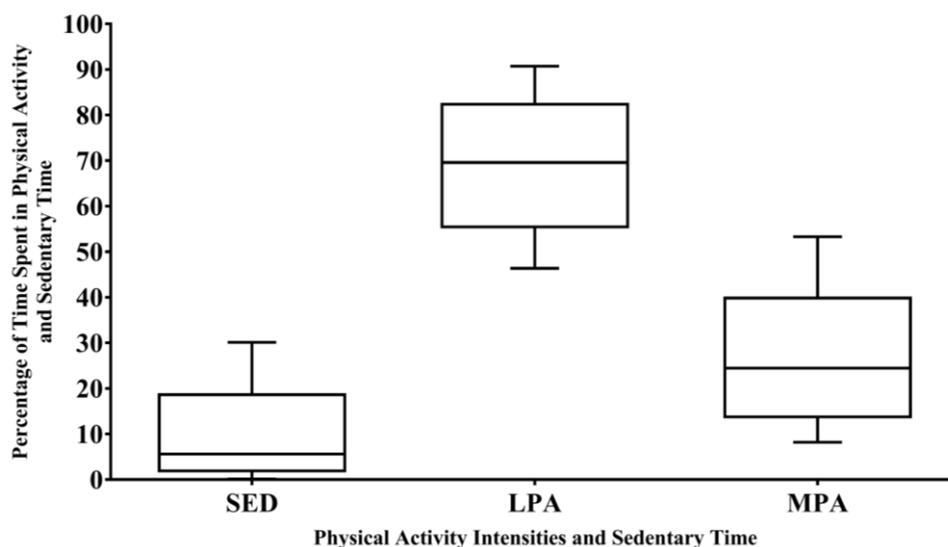


Figure 1. Proportion of time spent in physical activity and sedentary time during a planned burn operation. Data are displayed as median and 1st and 3rd quartile with the range between minimum and maximum values. SED = sedentary time; LPA = light-intensity physical activity; MPA = moderate-intensity physical activity.

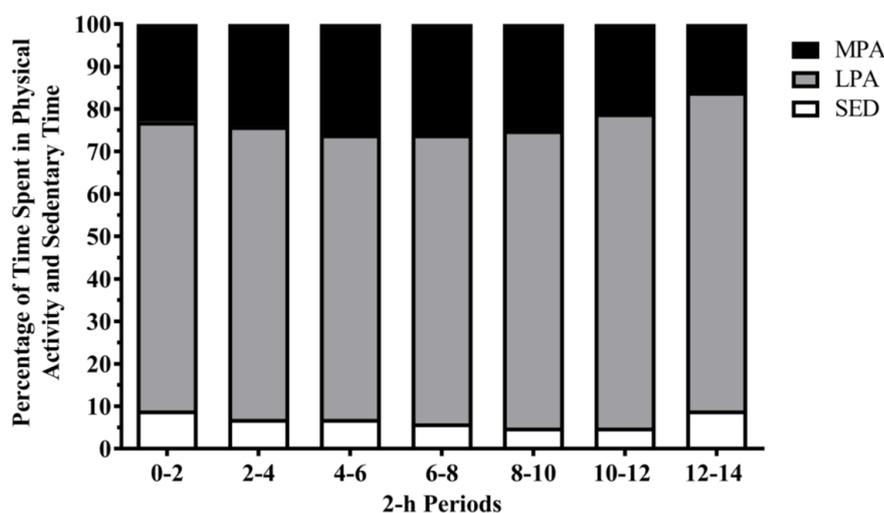


Figure 2. Proportion of time spent in physical activity and sedentary time during each 2-h period across a planned burn shift. Data are displayed as mean values (SD). SED = sedentary time; LPA = light-intensity physical activity; MPA = moderate-intensity physical activity. 0–2 h: $n = 34$; 2–4 h: $n = 34$; 4–6 h: $n = 34$; 6–8 h: $n = 34$; 8–10 h: $n = 33$; 10–12 h: $n = 31$; 12–14 h: $n = 30$.

3.3. Associations Within- and Between-Shifts

The associations between the number of minutes spent in each level of physical activity intensity and SED between temporally adjacent shifts or 2-h period pairs are shown in Tables 2 and 3.

No significant associations were observed between SED or any level of physical activity between consecutive planned burn shifts and within consecutive 2-h periods.

Table 2. Associations between time (min) spent in different physical activity intensities or sedentary time between pairs of consecutive shifts.

	b (95% CI)	p Value
SED _{S1} → SED _{S2}	−0.43 (−1.02 to 0.16)	0.152
LPA _{S1} → LPA _{S2}	0.01 (−0.08 to 0.09)	0.987
MPA _{S1} → MPA _{S2}	0.14 (−0.16 to 0.43)	0.356
SED _{S1} → LPA _{S2}	−0.01 (−1.11 to 1.09)	0.992
SED _{S1} → MPA _{S2}	0.47 (−0.56 to 1.49)	0.372
LPA _{S1} → SED _{S2}	−0.03 (−0.08 to 0.02)	0.227
LPA _{S1} → MPA _{S2}	0.03 (−0.05 to 0.11)	0.420
MPA _{S1} → SED _{S2}	−0.12 (−0.30 to 0.05)	0.175
MPA _{S1} → LPA _{S2}	−0.02 (−0.34 to 0.30)	0.885

Adjusted for age, sex, firefighting experience, wear time, sleep and BMI; b: parameter estimate; SED: sedentary time; S1: shift one; S2: shift two; LPA: light-intensity physical activity; MPA: moderate-intensity physical activity.

Table 3. Associations between time (min) spent in different physical activity intensities or sedentary time between pairs of 2-h periods within a shift.

	b (95% CI)	p Value
SED _{P1} → SED _{P2}	−0.23 (−0.52 to 0.06)	0.116
LPA _{P1} → LPA _{P2}	0.003 (−0.06 to 0.06)	0.993
MPA _{P1} → MPA _{P2}	0.06 (−0.18 to 0.30)	0.606
SED _{P1} → LPA _{P2}	0.36 (−0.17 to 0.89)	0.183
SED _{P1} → MPA _{P2}	−0.14 (−0.70 to 0.41)	0.618
LPA _{P1} → SED _{P2}	0.01 (−0.08 to 0.04)	0.710
LPA _{P1} → MPA _{P2}	−0.01 (−0.7 to 0.05)	0.793
MPA _{P1} → SED _{P2}	−0.04 (−0.18 to 0.09)	0.525
MPA _{P1} → LPA _{P2}	−0.02 (−0.25 to 0.22)	0.872

Adjusted for age, sex, firefighting experience, wear time, and BMI; b: parameter estimate; SED: sedentary time; P1: 2-h period one; P2: 2 h period two; LPA: light-intensity physical activity; MPA: moderate-intensity physical activity.

4. Discussion

This study examined firefighters' SED and physical activity levels during planned burn operations. Firefighters spent 69% of a planned burn shift engaged in LPA. No significant associations were observed between physical activity or SED during one shift or 2-h period with the following shift or 2-h period, respectively, suggesting that the physical activity that a firefighter engages in during one shift (or 2-h period) does not subsequently affect their physical activity levels in the subsequent shift (or 2-h period).

This is the first study to examine firefighters' physical activity and SED during planned burn operations, finding that ~6%, 69%, and 24% of a whole planned burn shift was spent in SED, LPA, and MPA, respectively. A negligible 0.19 min (<0.01%) was spent in VPA. Similar patterns of physical activity engagement were observed within-shifts. This indicates that, across an average 10.4-h shift, firefighters engage in physical activity of at least a light intensity for 94% of this time (i.e., 9.7 h). This highlights the need for firefighters to sustain their engagement in physical activity over long time periods. Whilst these findings are similar to the physical activity levels reported in wildfire settings by Vincent and colleagues [8], they largely contrast other published wildfire studies. For example, Raines and colleagues [11] found that firefighters spent only 3% of a 2-h period engaged in MPA, which is considerably lower than the within-shift findings from the present study. Across whole wildfire shifts, previous research has reported that the proportion of time spent in MPA ranged from 5% to 23% [8,14,28].

Taken together, these findings suggest that firefighters may engage in more physical activity during planned burns compared with wildfires, which is somewhat surprising given the contrasting contexts (i.e., routine operations vs. emergency situations). Differences in monitoring approaches may explain these contrasting findings, which include the lack of non-wear criteria in previous studies (which can result in an overestimation of SED [29]), wear location (chest, jacket pocket, wrist [11,12,14,19]), and the definition of MPA [17]. However, it is also possible that higher activity levels observed during planned burns reflect a different task emphasis across a shift. For instance, during a planned burn, there may be more walking during both the ignition, patrolling, and suppression phases. This can be seen in Figure 1 and Table 1, where there was a large range between the average time spent in different physical activity intensities. This may have also resulted from a range of fire suppression tasks [30], differing roles (i.e., monitoring the area or suppressing a spot fire [9]) or differences in the terrain [31]. Furthermore, it appears that several firefighters engaged in a higher percentage of MPA when the monitors were worn for longer (data not presented), though wear time was included in the models to adjust for the impact of wear time on activity levels. It is possible that this reflects the differences in the requirements of the shift or the location (i.e., longer shifts require greater engagement in physical activity). Quantifying the MPA required across different roles during planned burn work will directly inform workforce health and safety programs for firefighters. In contrast, the increased focus on suppression duties during emergency fires may require less ambulation and, therefore, return lower physical activity counts. Exploring the patterns of physical activity and the tasks that contribute to these patterns should be a focus of future research.

This is the first study to examine associations between time spent in different physical activity intensities or SED during any given planned burn shift or 2-h period and the time spent in these activities in the following day or 2-h period. No significant associations were observed between- or within-shifts, which suggests that the amount of physical activity or SED a firefighter engages in during one shift (or 2-h period) does not result in decreased (or increased) physical activity or SED levels in the following time period (i.e., not consistent with the activitystat hypothesis [15]). This largely supports the findings of Vincent and colleagues [8], who used this analytical approach to examine the activity levels of firefighters during wildfire suppression. Whilst they found that firefighters were able to maintain their activity levels between shifts, they also found that the amount of LPA engaged in one shift was associated with increased LPA and MPA in the following shift [8]. This contrasts the current study where no such observations were noted. Interestingly, despite the differences in analytical approaches, the within-shift findings are consistent with the previous wildfire literature [11,12]. Overall, these findings suggest that firefighters will adopt self-pacing strategies that allow them to sustain their physical activity and SED across the shift [32]. This is further supported by the data in Figure 2, which shows firefighters spend the vast majority of their shift performing LPA. Arguably, engagement in LPA would be more sustainable across a shift compared with higher activity intensities. These findings may also be attributable to, in part, the experience of the firefighters. In this study, the sample had eight years of firefighting experience. It is possible that such pacing strategies may develop with experience, as has been previously found in athletes [33]. Therefore, future research is needed to look into the possible moderating effects of different variables, such as firefighter experience, on the within-shift physical activity patterns.

It should be noted that it is difficult to compare the current findings to previous research that has used between-person or between-group designs to examine firefighters' physical activity levels during wildfire suppression, which have shown mixed findings to date. Such designs may be affected by day-to-day variations in ambient temperature [7], hydration [11–13], nutrition [34], or suppression duties that could explain the more commonly observed decreases in physical activity or SED between shifts or 2-h periods. Using a within-person design (i.e., time points clustered within individuals), the results from the current study suggest activity levels are maintained within- and between-shifts despite day-to-day changes in the working environment, including different tasks, duties, weather conditions, and working locations [9,10,31]. Importantly, as these findings suggest that physical activity

levels during one shift (or one period of a shift) do not affect activity levels in the following shift (or shift period), it appears that operational modifications such as more regular breaks and additional personnel may not be needed to ensure planned burn operations are effectively completed.

Overall, the lack of associations between physical activity or SED across consecutive planned burn shifts and within planned burn shifts (2-h periods) is interesting given the finding that firefighters spent ~153 min engaged in MPA across an average shift. With Australian physical activity guidelines recommending that adults aged 18–64 year accumulate at least 150 min of MPA a week [35], these results highlight that one planned burn shift is equivalent to the minimal amount of physical activity that should be accumulated a week to benefit health. Indeed, firefighters accumulated up to four times the volume of physical activity in one shift compared with daily population estimates [36,37]. If this high amount of physical activity is performed regularly, there is the possibility that there may be a benefit to aerobic conditioning [38]. The activity levels also lend support to previous observations that aerobic capacity is one of the important fitness components (along with strength endurance [39]) for land management firefighters [40]. In order to identify how firefighters maintain high volumes of physical activity during long planned burn shifts, future research should examine how physical activity is accumulated (i.e., frequency and duration of activity bouts). This will provide crucial insights into potential pacing strategies and may help to identify optimal activity patterns that could inform workforce training programs to optimise the conditioning and minimise the fatiguing impacts of fireground work.

The strengths of the current study include using a multilevel modelling approach to explore physical activity associations, which accounts for within-person factors of non-independent data [24]. Furthermore, this is the first study to explore physical activity and SED associations within a firefighting shift, providing some context to previous pacing suggestions. However, this study used a convenience sample drawn from multiple Australian fire and land management agencies. Although this method has been used previously to collect data for a firefighting population [8], a small sample resulted; therefore, it is possible that the current study may be underpowered. This may contribute, at least in part, to the lack of significant associations observed. Another potential limitation is that data were collected in 1-min epoch lengths, which may have underestimated the reported VPA, as firefighters typically engage in high-intensity suppression tasks for short durations (e.g., <1-min [30]). Future research should investigate utilising shorter epoch lengths to allow a more detailed assessment of VPA. Furthermore, the Actical accelerometer was worn on the wrist, which has been found to more accurately capture upper body movements [19] that are involved in the majority of firefighting suppression tasks [30]. However, the wrist location may also record motions that are not related to the suppression task, such as fidgeting [19]. In addition, the current analyses were adjusted for several covariates identified a priori (age, sex, BMI, wear time, experience, and sleep duration). However, the study was not powered to examine the moderating effects of these covariates on firefighters' physical activity and SED levels. It is recommended that future researchers examine the physical activity patterns (including associations) across different samples (e.g., older and younger firefighters and those with a larger or smaller BMI) of firefighters to identify whether there are specific cohorts who may need more targeted safety controls to sustain their physical activity and SED across one shift or multiple shifts.

5. Conclusions

Firefighters predominantly engaged in LPA during a planned burn shift. Further, firefighters are able to maintain their levels of SED and physical activity across consecutive planned burn shifts and within 2-h periods. Additional research is required to capture levels of VPA during firefighting using more high-resolution analyses and to recruit larger samples to enable the rigorous examination of potential moderators and susceptible cohorts of firefighters (e.g., those who are older and those with larger BMI).

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