

The effects of sleep on firefighter occupational performance and health: A systematic review and call for action

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ABSTRACT

Firefighting is a mentally and physically demanding profession which is compounded by poor sleep due to shift schedules commonly used by fire departments. Compared to other professions, firefighters are at high risk for musculoskeletal injuries, mental illnesses, and cardiovascular diseases. The purpose of this study was to systematically review the effects of sleep on firefighter occupational performance and health. A search was conducted for studies that conducted a quantitative analysis involving sleep and occupational performance in firefighters. Relevant data were extracted and study quality evaluated with Newcastle-Ottawa Scale. There were 15 articles meeting the inclusion criteria with a total sample of 1591 (1539 male, 52 female) firefighters. We found that firefighters with poor sleep measures had worse cognitive performance and overall health, but physical capabilities were not impacted by acute sleep restriction. However, chronic poor sleep would likely negatively impact physical performance due to being associated with a decline in numerous health measures. To avoid sleep-related declines in occupational performance fire departments should consider the consequences of shift schedules on the performance and health of firefighters. Furthermore, sleep education interventions, the use of wearables to monitor, recovery and sleep health screening appear beneficial based on prior research.

1. Introduction

Adequate sleep is needed for optimal physical performance [1] and cognitive functioning [2,3] as well as overall well-being [4]. Additionally, impaired sleep may increase the risk of sustaining a musculoskeletal injury in highly physically demanding jobs, such as firefighting [5,6]. It is recommended that adults obtain 7 to 9 h of quality sleep per night for optimal functioning [7]. However, many adults are characterized as experiencing poor sleep hygiene due to having less than 7 to 9 h of sleep, frequent awakenings, disordered breathing, difficulty falling asleep, low sleep efficiency, feelings of day-time sleepiness, and needing medication to sleep [8]. Firefighters are known to suffer from poor sleep hygiene [9–11], which is associated with a number of health consequences, such as obstructive sleep apnea [12], decreased response time [2], hypertension [12], cardiovascular disease [13,14], obesity [15], mental health [16,17], impaired balance. [18], and physical functioning [1].

The International Association of Fire Chiefs and the United States Fire Administration [19] previously reported the effects of poor sleep on the duties and career of firefighters using measures such as psychomotor vigilance, reaction time, alertness, fatigue, mood, physical health and overall quality of life [19]. One contributor to poor sleep hygiene

is the work-shift schedules (e.g., 24 h on and 48 h off; 48 h on and 96 h off) commonly employed by firefighting departments. Shift schedules exceeding 12 h during a 40+ hour work week have been linked to deteriorating performance and increased injuries [20]. In general, shift workers are at a higher risk of cognitive deficits, workplace accidents and cardiovascular-related health issues [21]; however, for firefighters the consequences may be amplified due to the innate unpredictability and intensity of firefighting environments.

During a shift, firefighters experience cognitive demands such as sustaining attention, accessing long- and short-term memory, processing information, reacting to events, and communicating often in emergency situations [22,23]. Specifically for firefighters, psychomotor vigilance may be sensitive to declines in occupational-related cognitive functioning [24,25]. Firefighters are also required to perform strenuous physical tasks (e.g., running, jumping, carrying heavy loads, and dragging victims to safety) in challenging unpredictable conditions [26,27]. Thus, firefighters must maintain high levels of physical fitness to complete the physical requirements of the job [28,29]. These physical demands of firefighting are often associated with high musculoskeletal injury rates [30], resulting in substantial health costs [31]. Furthermore, when physical tasks are concurrently performed with cognitive tasks, biomarkers

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of physical exertion increase [32] and physical performance capabilities are impaired [33]. Since poor sleep hygiene may negatively influence simple cognitive and functional tasks [2,3,18,34], poor sleep hygiene may be even more impactful on firefighters considering the high cognitive and physical demands of their occupation.

Since the 2007 report [19], more research has been conducted to increase knowledge on the effects of poor sleep hygiene on firefighter safety and ability to perform occupational duties [35–39][59]. A 2018 narrative review by Vincent et al. highlighted the consequences of poor sleep as impaired cognitive, but not physical, performances in wildland firefighters [41]. The unique aspects of wildland firefighters shifts [42] brings into question the generalizability of this conclusion to all firefighters. Furthermore, many of the studies reviewed were conducted in simulated conditions [37,43–46]. Although field studies offer the ability to measure the responses of firefighters in austere environments, it is rather difficult to reliably collect data in these conditions. Yet, non-invasive wearable sensors can be instrumented for estimating total physical activity and heart rate measures in attempt to quantify physical stress and the respective internal physiological responses to surrounding stressors during occupational tasks [47]. However, events during the field data collection are uncontrollable and for this reason simulated events are often created to mimic operational tasks and stressors that firefighters may encounter during operations. Simulations allow necessary data collection procedures in a controlled environment without interfering with necessary actions that may impair operational tasks. Thus both field and simulation research paradigms are complimentary and collectively can offer valuable insight. In order to further research, develop interventions and strategies to improve firefighters sleep health a systematic review of the literature is needed at this time. Therefore, the aim of this systematic literature review was to identify the effects of sleep on occupational performances of firefighters during real-life and simulated firefighting conditions.

2. Methods

The study selection, search criteria, data extraction, and assessment of study quality were defined a priori and informed by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [48]. The protocol of this systematic review was registered with PROSPERO (registration #: CRD42020212916).

2.1. Eligibility criteria

An initial literature search was conducted to identify reliable and valid sleep data collection methodologies and metrics to be included in the current review. The criterion for measuring sleep, polysomnography, is often difficult to use in practical settings; thus, more common methodologies, such as wearable sensors and self-reported questionnaires, were included in the current review. These methods are often considered to be reliable and valid [49], but their validity may be subject to the device and sleep metric assessed. Studies were required to meet the following criteria: (1) participants described as professional or volunteer firefighters, (2) examined associations or effects of sleep measures and occupational performance (physical or cognitive) or acute biomarkers of health, (3) conducted via empirical study designs (cross-sectional, cohort, quasi-experimental or experimental), (4) written in English, and (5) published in the last 25 years (1996 to 2021). Studies were excluded for the following: (1) peer-reviewed full-text articles were not able to be retrieved, (2) utilized a drug as part of an experimental or control group, or (3) the article was a single case study, review, commentary, or opinion article excluding original data.

2.2. Search strategy and study selection

Two authors (CF and MT) conducted individual literature searches on three electronic databases (PubMed/Medline, EBSCO (CINAHL), and

the Cochrane Library) in February 2021. The keywords used in the search string are listed in Table 1. Boolean logic operators were used such that the sample of firefighters and measure of sleep were combined with any of the performance or health outcome measures [i.e. (1 AND 2) AND (3 OR 4 OR 5 OR 6)].

The search results were exported to a data base in Microsoft Excel (version 16.46, Microsoft Excel, Redmond, WA, USA) and duplicated removed ($n = 48$). Next, titles and abstracts were screened by multiple authors (CF, MT) for relevance and eligibility. The full text of articles retained after screening ($n = 28$) were independently assessed against selection criteria by two authors (CF, MT). If agreement was not reached, discussion was made with the assistance of an additional authors (JRM, JJM). Reference lists from included articles were searched for relevance and used to identify any articles that were missed during the initial search.

2.3. Data extraction

For all eligible studies, data were extracted and tabulated independently by two authors (CF, MT). A data extraction spreadsheet was developed based on the Cochrane Consumers and Communication Review Group's data extraction template [50]. Extracted information included (a) author and year, (b) study design, (c) country, (d) participant description and sample size, (e) sex and age, (f) outcome measures, and (g) sleep variables. Due to the overall heterogeneity (i.e., country participants were located, procedures, statistical approaches, sleep measures, occupational performance measures, health measures) of the included studies the authors determined a qualitative synthesis of the results only without a meta-analysis was appropriate [51].

2.4. Study quality assessment

The methodological quality for each study in the review was assessed using the Newcastle-Ottawa Scale (NOS). Quality assessment scores were independently determined by two authors (CF and MT) and any disagreements were resolved by discussion and consensus with a third review (JRM). Articles were rated using a number of stars in three domains and considered as poor (selection, ≤ 1 ; compatibility, 0; outcome, ≤ 1), fair (selection, 2; comparability, 1–2; outcome, 2–3) or good (selection, 3–4; comparability, 1–2; outcome, 2–3).

3. Results

3.1. Search results

The literature search initially identified 295 articles (Fig. 1). There were 219 articles eliminated based on inclusion/exclusion criteria. During the data extraction process 3 additional articles were retrieved from a forward citation search [43,53,54]. A total of 15 articles were included in the current review (Table 2).

3.2. Characteristics of included studies

The sample size for each included study ranged from 10 [53] to 705 [55] participants, totaling 1591 (1539 male, 52 female) professional or volunteer firefighters in the current systematic review. Data were collected from 5 different countries (Australia [36,37,39,43–46,56], United States [35,59]), Canada [10,53,54], Japan [57], Korea [55]), during both simulated or laboratory ($n = 9$) [37,38,41,44–47,56,57] and field ($n = 6$) research settings [10,59,53,54,57,35]. A majority ($n = 11$) of the studies utilized wildland firefighters (Table 2 and Table 3). Results of study quality assessment are in Table 4. All articles were rated as good quality in accordance with the NOS evaluation criteria.

Table 1
Search terms and strategies.

Item	Desired outcome	Search terms
1	Sample of firefighters	firefight* OR fire fight* OR fighting fire* OR smokejumper*
2	Sleep measure	sleep* OR PSQI OR fatigue
3	Physical Performance	performance OR physical OR fitness OR assessment
4	Cognitive performance	mental OR cognitive OR reaction time OR response time OR decision making
5	Miscellaneous performance terms	musculoskeletal OR injury OR soreness OR strength OR endurance OR balance
6	Health	health OR physiology OR biomarker

* used to truncate root word and find all words with alternate endings.

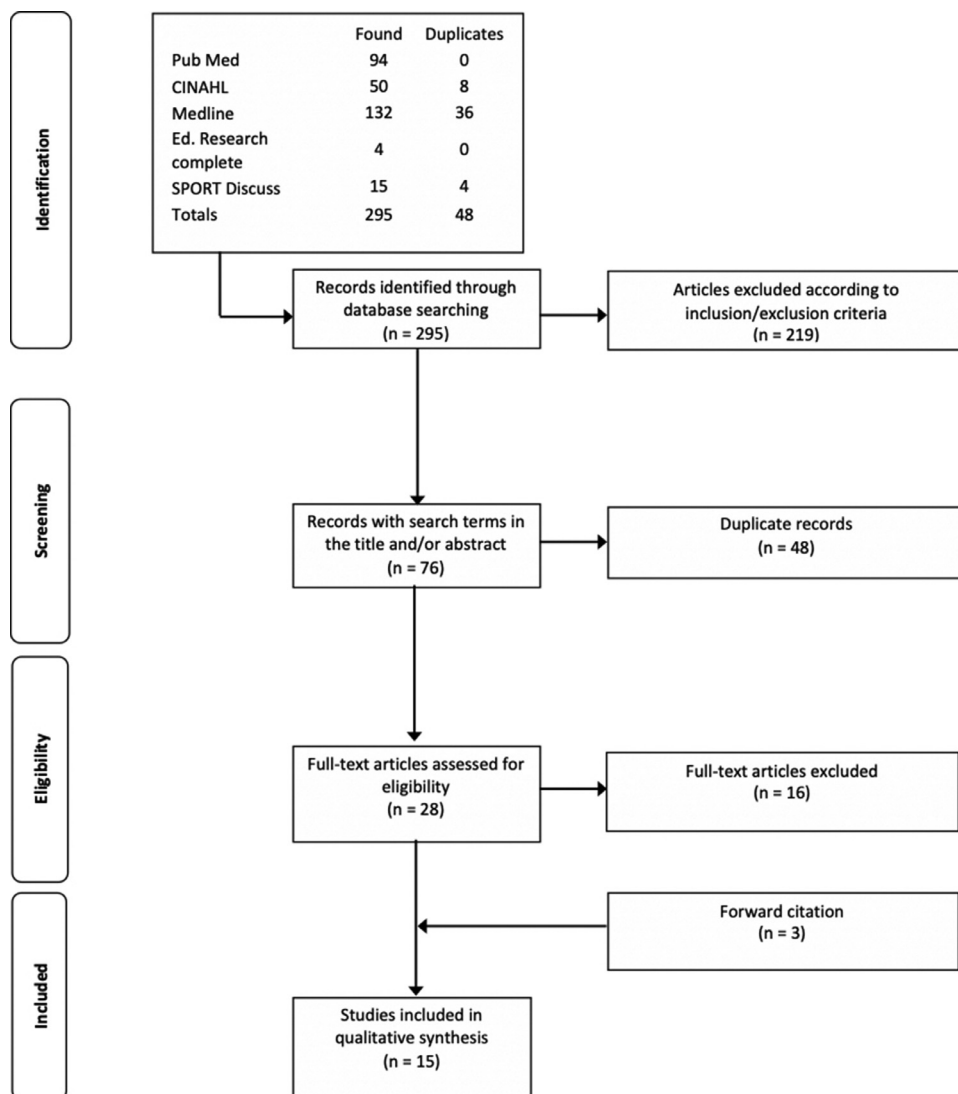


Fig. 1. Search strategy and result.

3.3. Sleep measures

Sleep was assessed subjectively using self-reported questionnaires [10,57] and fatigue scales [35,37,55,59], as well as objectively using polysomnography [36,45,46,56] and actigraphy [10,39,53,54,59]. A variety of sleep measures were reported: total sleep time (TST), time in bed (TIB) sleep efficiency (TST/TIB * 100), various stages of sleep defined in the literature, wake after sleep onset minutes (WASO), sleep onset latency (SOL), rapid eye movement (REM), sleep efficiency, sleep disruption, daytime sleepiness, fatigue and sleep quality. Notably, several studies used controlled sleep conditions [36,37,43–46,56], while other studies monitored sleep during routine shifts without controlling sleep [10,39,53,54,56,57,59].

3.4. Physical performance

Two studies by Vincent and colleagues investigated the relationship between sleep and performance of physical firefighting tasks [36,46]. Neither study found an effect of sleep restriction (4 vs. 8 h per night) on physical task performance.

3.5. Cognitive performance

A consistent finding in the literature was a negative effect of poor sleep on measures of cognitive performance. Seven studies reported on the relationship between sleep and firefighter cognitive performance [10,35,37,53,54,56,59]. Five studies examined the effect of sleep on

Table 2
Characteristics and results of included studies.

Study	Participants	Inclusion/ Exclusion Criteria	Procedures	Sleep		Occupational Performance		Health	
				Measure	Results	Measure	Results	Measure	Results
Cvirm et al. (2017)	N = 61 Wildland firefighters (22 males & 3 females): Control group (n = 25); Awake group (n = 25); Awake/hot group (n = 11)	Active volunteers from 6 Australian Fire Service departments.	A field based 3-day, 4-night multi-day simulated wildfire suppression consisted of a baseline night with 8-h of sleep, followed by 2 nights with either 8-h or 4-h of sleep for the control or awake and awake/hot conditions, respectively. For the control and awake conditions, day and nighttime temperatures remained between 18 and 20 °C throughout the protocol.	TST, TIB, SE, Stage N1, Stage N2, Stage N3, WASO, SOL	N1 decreased significantly by night 2, while N2 and recovery sleep significantly decreased over nights 1 and 2, in both the awake and awake/hot conditions compared to the control condition.	None	None	PA was a co-variate in models examining the effects of sleep restriction on measures of sleep during a simulated firefighting condition	PA was a significant co-variate only for sleep onset latency.
Ferguson et al. (2016)	N = 88 Wildland firefighters (77 males & 11 females): Normal sleep/cool (n = 29); Normal sleep/hot (n = 20); Sleep restricted/cool (n = 26); Sleep restricted/hot (n = 13)	Active volunteer rural Australian firefighters. Excluded if subjects had current or pre-existing injury, diagnosed sleep disorder, and / or pregnant.	A field-based ground-fire simulation took place over 3 consecutive 12-h day shifts. The intervention spanned 4-days, including familiarization of the tasks, adaption to sleeping conditions on the evening prior to testing, and a morning testing session on day 4.	SFC	All measures of SFC showed the relative best performance in being sensitive to changes for those participants in the most stressed sleep restricted/ hot condition.	PVT, Memory task, Stroop Color Word Test, Go-No-Go, Occupational Safety Performance Assessment Test	PVT showed a greater responsiveness than Go-No-Go in the sleep restricted/ hot condition compared to the other less stressed conditions.	SFC, Alertness, motivation, pre-performance	The SFC had the greatest responsiveness to the experimental manipulations and the highest correlation with the objective measures.
Haddock et al. (2013)	N = 458 Career firefighters (male)	Active firefighters from the International Association of Fire Chiefs Missouri Valley Region.	Sleepiness was assessed in a field setting using the ESS from 11 randomly selected fire departments in the Midwestern United States.	ESS, EDS	Majority of firefighters scored in the normal range of ESS on both on-duty and off-duty days. Firefighters who reported EDS while at work were much more likely to report insufficient sleep while on duty.	None	None	Depression & blood pressure	EDS was associated with significantly higher rates of depressive symptoms both on duty and off duty. Subjects with EDS on duty had slightly lower systolic blood pressures compared with those without on-duty EDS.

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Table 2 (continued)

Study	Participants	Inclusion/ Exclusion Criteria	Procedures	Sleep		Occupational Performance		Health	
				Measure	Results	Measure	Results	Measure	Results
Jay et al. (2016)	N = 20 Wildland firefighters (17 males & 3 females); SDB group (n = 8); Non-SDB group (n = 12)	Active volunteer firefighters from 5 Australian Fire Service departments.	A field based 3-day-4-night fire simulation. Subjects were retrospectively allocated to either a SDB or a non-SDB group based on their ODI. The simulation began with an 8-h baseline sleep followed by 2-nights of restricted (4-h) sleep and an 8-h recovery sleep. All sleeps were recorded using electroen-cephalography as well as oxygen saturation. During the day, participants completed neurobehavioral tasks.	TST, SE, Stage N1, Stage N2, Stage N3, REM, WAS, SOL, ROL, SQ	The SDB group had less TST and REM and greater WASO compared to the non-SDB group. Participants in the SDB group slept 42 min less on the baseline night.	Response time, PVT, SFC	Both SDB and non-SDB group's response time performance was significantly increased on the experimental nights compared to baseline and recovery nights. Pairwise comparisons showed that fatigue scored on the SFC on the baseline day were significantly lower compared to fatigue on experimental days.	ODI	SDB group had significantly higher ODI across all sleeps compared to non-SDB.
Jeklin et al. (2020)	N = 30 Wildland firefighters (male)	Active type-1 wildland firefighters from two fire services in British Columbia.	Sleep and fatigue measures were collected in a field setting during a 17-day wildland firefighting deployment. Days 1–14 consisted of active fire line workdays and 15–17 were rest days. Sleep and fatigue measures were collected at basecamp at the end of each active day.	Triaxial actigraphy/ accelerometer	There was no significant effect on TST, overall TST decreased an average of 12 min from day 1 to day 14. On rest days firefighters sleep on average 11 min longer compare to active days.	PVT, VAS- fatigue and alertness	Firefighters showed significantly slower reaction times on day 13 compared to day 5. Firefighters self-reported significantly higher levels of fatigue on day 16 compared to day 5. There was a significant decrease in reported alertness from day 3 compared to day 13.	None	None
Jeklin et al. (2021)	N = 10 Wildland firefighters (7 male & 3 female)	Highly specialized management personnel from the British Columbia Wildfire Service	Sleep and fatigue measures were collected in a field setting during a 14-day wildland firefighting deployment. Sleep and HRV were measured daily at the end of duty at basecamp. Cognitive functioning was assessed on day 1,5,10, and 14.	Triaxial actigraphy/ accelerometer	TST significantly decreased compared to controls on day 1, 3, 4, and 12. There was a significant positive association between HRV and TST.	Simple reaction time, choice reaction time, discrimination reaction time, and VAS fatigue and alertness	No significant differences were shown in the 3 reaction time tests. Firefighters reported significant decreases in alertness on days 11 and 13 compared to day 1. There was a significant inverse association between fatigue.	None	None

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Table 2 (continued)

Study	Participants	Inclusion/ Exclusion Criteria	Procedures	Sleep		Occupational Performance		Health	
				Measure	Results	Measure	Results	Measure	Results
McGillis et al. (2017)	N = 21 Wildland firefighters (male)	Active Canadian firefighters who were excluded if subjects had current or pre-existing injury.	Sleep and fatigue measures were collected during a field-based setting using actigraphy wrist watches and questionnaires during non-fire (Base) and fire (Initial Attack and Project) deployments.	Actigraphy, SE, WASO, TST	Initial attack TST was significantly lower than base TST by 84.4 min. Initial Attack had a significantly lower SE than that observed for Project fires	Subjective fatigue, PVT	Subjective fatigue and PVT scores during morning periods were significantly higher for Initial Attack compared with Project fire. No other significant differences between groups within both measures were identified.	None	None
Stout et al. (2020)	N = 45 Firefighters (44 males & 1 female)	Active firefighters in Florida, USA; excluded if they reported taking medication to promote sleep or linked to excessive drowsiness, if they had substance abuse disorders, and/or major sleep disorders.	A field-based intervention was conducted to determine the impact of shift schedules on sleep duration, sleep quality, processing speed, sustained attention, vigilance, and mental health. Assessments were conducted at the start and end of shift.	PSQI, Actigraphy, WASO, SE	Mean PSQI score was indicative of poor sleep quality. Actigraphy showed the average workday sleep duration was 5-h 20.99 min. WASO on-shift and off-shift scores were significantly different; the WASO on-shift mean was 29.17 min greater than the WASO off-shift. 90.2% of the population had poor SE.	PVT, processing speed	WASO was significantly correlated with the change score for processing speed and PVT.	Beck Depression Index, Quality of life, Anxiety, Depression, Post Traumatic Stress	Mean score on the Beck Depression Index was 6.63. The average Post Traumatic Stress Disorder score was 9.4. The average General Anxiety Disorder Scale score was 6.84. Quality of Life Inventory average score was 52.11, which is indicative of an average quality of life satisfaction.
Takeyama et al. (2005)	N = 11 Firefighters (male)	Active Japanese firefighters worked 24-h every other day. Subjects were excluded if unable to maintain schedule over the 17-day period of the intervention.	Firefighters were assigned to 1 of 5 work periods during a field-based intervention. They took naps in individual rooms during night duty, except when on night shift or when called out on an emergency. Subjective and objective tasks were measured before and after work and following breaks during their 24-h shift. HRV was also recorded to evaluate autonomic nerve activity.	Sleep & fatigue questionnaire (Factor I: drowsiness & tiredness; Factor II: difficulty in concentrating; Factor III: projection of physical disintegration)	During the 5 periods in 24-h shifts. Factor I complaints before and after the night shift in P4 were significantly higher than during P2 and P5. Factor III complaints at 07:30 during P4 were significantly higher than in P1, P2, and P5.	Critical Flicker Fusion Frequency, Three-Choice Reaction Time	No significant differences among the results of during the Three-Choice Reaction Time shift periods were observed. The changes in Critical Flicker Fusion Frequency during P2, P3, and P4 were fewer than those during P1 and P5.	HR & HRV	HR during P5 were significantly higher than those in other shift periods. The values of high frequency HRV during P3 and P4 tended to be higher than during P1, P2, and P5, but there were no significant differences. The value of the low frequency to high frequency ratio of HRV of P4 was significantly lower than during P5.

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Table 2 (continued)

Study	Participants	Inclusion/ Exclusion Criteria	Procedures	Sleep		Occupational Performance		Health	
				Measure	Results	Measure	Results	Measure	Results
Vincent et al. (2015)	N = 35 Wildland firefighters (30 males & 5 females): Control group (n = 18); Sleep restriction (n = 17)	Active volunteer firefighters during 2012/2013 or 2013/2014 Southern Australian fire season. Participants were excluded if self-reporting data was incomplete or water damaged.	Firefighters were matched and randomly allocated to the control group (8-h) or a sleep restricted group (4-h) in a field-based intervention. Performance on physical work tasks was evaluated across 3-days. In addition, HR, core temperature, and worker activity were measured continuously. Rate of perceived exertion and effort sensation were evaluated during the physical work periods.	Polysomnography	During the 2 experimental nights, mean sleep duration was lower in the sleep restricted group compared to control group.	HR, Core Temperature, & Physical Task Performance	No differences between sleep groups were found.	PA	Sleep restricted group was less physically active during the simulation.
Vincent et al. (2016)	N = 40 Wildland firefighters (31 males & 9 females)	Active firefighters from 4 Australia's state fire agencies; excluded if unable to perform vigorous exercise and/or had a sleeping disorder.	Volunteer firefighters wore activity monitors to measure PA and sleep duration during a field-based intervention. Subjects tracked shifts worked and duties in a work diary.	Activity monitors	Firefighters' average total sleep time between consecutive shifts during wildfire deployments was 6.1 ± 1.7 -h.	None	None	PA intensity	Firefighters, on average engaged in light PA for 87.7% of their shift. Sleep did not have a moderating effect on PA.
Vincent et al. (2018)	N = 31 Wildland firefighter, HOT group (18 total, 14 male, 4 female) HOT + SR group (13 total, 12 male, 1 female)	Active career and volunteer firefighters from 4 Australia's state fire agencies; excluded if living in hotter climates to control for heat acclimation.	Firefighters were fitted with activity monitors 2 days prior to the study and maintained their normal sleep schedule. The field-based simulation took places over 3 days, which consisted of a group who was exposed to heat and a group that was exposed to heat and restricted to 4-h of sleep. The simulation involved physical work circuits, physiological work, cognitive testing, and rest.	Polysomnography	There was no difference between sleep during the intervention and the two baseline sleep nights in either group.	Physical task performance	There was no significant difference between groups. The HOT+SR group did report higher levels of perceived exertion for 2 of the 6 tasks.	None	None

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Table 2 (continued)

Study	Participants	Inclusion/ Exclusion Criteria	Procedures	Sleep		Occupational Performance		Health	
				Measure	Results	Measure	Results	Measure	Results
Wolkow et al. (2015)	N = 35 Wildland firefighters (30 males & 5 females): Control group (n = 18); Sleep restriction (n = 17)	Active volunteer and career firefighters from fire services across Australia. Subjects excluded if they had been diagnosed with heart disease, diabetes, respiratory or sleep restrictions.	A field-based ground-fire simulation took place over 3 consecutive 12-h day shifts. The intervention spanned 4-days, including familiarization of the tasks, adaption to sleeping conditions on the evening prior to testing, and a morning testing session on day 4.	Polysomnography	Sleep restricted group slept significance less due to the protocol. There were no other differences in sleep between groups.	None	None	Cytokine response	Non-significant increase in interleukin-8 in the control group. Non-significant increase of interleukin-6 in both groups.
Wolkow et al. (2016)	N = 35 Wildland firefighters (30 males & 5 females): Control group (n = 18); Sleep restriction (n = 17)	Active rural volunteer and career firefighters from fire services across Australia. Subjects excluded if they had been diagnosed with heart disease or untreated sleep disorder in the 6 months prior to testing.	A field-based ground-fire simulation took place over 3 consecutive 12-h day shifts. The intervention spanned 4-days, including familiarization of the tasks, adaption to sleeping conditions on the evening prior to testing, and a morning testing session on day 4.	Polysomnography	Sleep restricted group slept significance less due to the protocol. There were no other differences in sleep between groups.	HR	Firefighters HR decreased by an average of 5 beats per min during the simulation. There were no significant differences between groups.	Cortisol response	Cortisol levels in the sleep restricted group increased significantly during the 2nd and 3rd day.
Yook et al. 2019	N = 705 Firefighter (male)	Active Korean firefighter between November 2016 and December 2017.	The Occupational Stress Scale was used to evaluate occupational stress; an exercise stress test was administered to measure participants' VO ₂ max; brachial-ankle pulse wave velocity was used to measure firefighters' arterial stiffness; their autonomic nervous system activities were analyzed to determine HRV; and the PSQI was used to assess their SQ in a lab setting. Subjects were placed in low-stress group, medium-stress group, and high-stress based on their occupational stress scores.	PSQI	There was a significant difference in SQ, SOL, sleep duration, SE, sleep disturbances, use of sleeping medication, daytime dysfunction, and total SQ scores according to occupational stress levels. There was a positive correlation between occupational stress and SQ.	VO ₂ max, HRV	VO ₂ max was significantly higher in the low-stress group than in the medium- or high-stress groups. No significant difference in HRV.	Occupational stress and arterial stiffness	There was a negative correlation between occupational stress and cardiorespiratory fitness. A positive correlation between occupational stress and arterial stiffness was observed.

Abbreviations: EDS, excessive daytime sleepiness; ESS, Epworth Sleepiness Score; FF, firefighter; HR, Heart rate; HRV, Heart rate variability; ODI, Oxygen Desaturation Index; PA, physical activity; PSQI, Pittsburgh Sleep Quality Index; RBANS; Repeatable Battery for the Assessment of Neuropsychological Status; REM, Rapid eye movement; SDB, Sleep Disordered breathing; SE, sleep efficiency; SFC, Sam-Perelli Fatigue Scale; SOL, Sleep onset latency; SQ, Sleep quality; TIB, Time in Bed; TST, Total Sleep Time; WASO, Wake after sleep onset.

Table 3
Conclusions and practical implications of included studies.

Study	Conclusion	Practical Implications
Cvirm et al. (2017)	PA was significantly associated with a decrease in SOL. Sleep restriction had a larger effect on sleep compared to the influence of heat.	Field measures of fatigue may optimize energy conservation and usage during physical tasks to optimize safety and performance while in a sleep deprived state.
Ferguson et al. (2016)	The SFC yielded the best sensitivity to measures of performance	Use of fatigue measures in the field may optimize fatigue risk management among firefighters and other occupations involving physical work.
Haddock et al. (2013)	Firefighters who work a 48-h work shift report EDS rate of 20.4% vs 12.2% for 24-h work shifts. Of the firefighters reporting on duty EDS 33.9% report having an injury in the last year.	A reduction in 48-h work shifts may decrease rates of EDS and injuries among firefighters.
Jay et al. (2016)	SDB showed a significantly greater decline in reaction time than non-SDB group.	Due to safety concern for volunteer firefighters with SDB findings recommend baseline SDB testing before acceptance as a volunteer for relevant agencies.
Jeklin et al. (2020)	14 consecutive active workdays lead to decreases in TST during the deployment and recovery period. The deployment was associated with increasing levels of fatigue.	Extended active fire deployment periods may be detrimental to the safety of firefighters.
Jeklin et al. (2021)	During a 14-day active deployment HRV was significantly associated with fatigue and sleep.	Monitoring HRV may be a viable tool to track sleep and fatigue during active fire deployment to preserve alertness.
McGillis et al. (2017)	Acute sleep restriction can have immediate effects on performance. Firefighters who had to respond to initial attacks showed significantly higher reaction times compared to base and project fires which are both more likely to fall into planned operations.	Implementation of sleep hygiene education and training on fatigue symptoms for firefighters may optimize performance during wildland fire suppressions.
Stout et al. (2020)	Firefighters experience less sleep while on the job then when off the job which has a significant effect on performance measures and cognitive functioning.	Minimal sleep disruption negatively affected work performance. Disruptions were not due to incoming emergency calls but rather sleeping environments at the fire stations. Adoption of black out shades and air purifiers may improve sleeping environments and reduce sleep disruptions.
Takeyama et al. (2005)	Psycho-Physiological function become impaired after 17 days of monitoring during normal conditions in a fire station during 24-h shifts. Mean scores for Critical Flicker Fusion Frequency and Three-Choice Reaction Time were lower for P2, P3, and P4 shifts, P3 and P4 shifts had significant less continuous sleep and also reported the highest level of subjective fatigue after the night shift. P2, P3 and P4 shift showed the highest standard deviation of high frequency HRV	Improvement of work conditions in Japanese fire stations may reduce subjective fatigue among firefighters working the nightshift.
Vincent et al. (2015)	During a 3-day, 2-night simulation subjects in the control group were able to adapt to physical performance measures and show an increase in performance while subjects in the sleep restriction group showed no increase in physical performance which might suggest that subjects were conserving energy due to the sleep restriction.	Firefighters combatting sleep restriction may altered their behavior to conserve energy for the physical simulation tasks. Use of fatigue measures in the field may optimize energy conservation and usage during physical tasks.
Vincent et al. (2016)	Sleep length did not affect physical performance when shifts averaged 11.0 ± 3.0 h with sleep averaging 6.1 ± 1.7 h during wildfire suppression with less than 1% of vigorous PA per day, less than 37% performing moderate PA per day, and more than 50% of the work time performing light PA.	Longer duration wildfire suppression simulations may be needed in future research studies to determine impact of occupational performance.
Vincent et al. (2018)	Two nights of restricted sleep in not a long enough duration to significantly influence physical task performance among firefighters. Slight increases in perceived exertion in the sleep restricted group may suggest some physical tasks require greater cognitive load.	Longer duration wildfire suppression simulations may be needed in future research studies to determine impact of occupational performance.
Wolkow (2015)	The intervention reported rises in cytokine activity and suggests that an extended simulation may be trigger significant stress responses.	Long-term fire suppression while sleep deprived may lead to chronically elevated cytokine levels enhancing chronic disease risk.
Wolkow (2016)	The findings support that 8-h sleep opportunities maintain normal cortisol levels mitigating chronic disease.	Sleep restriction during multi-day fire suppression can increase risk of cardiovascular disease.
Yook et al. 2019	The findings support that occupational stress levels are negatively associated with sleep quality. Furthermore higher levels of occupational stress levels were associated with lower cardiorespiratory fitness levels and higher arterial stiffness.	Firefighter occupational stress is related to risk of cardiovascular disease. Implementation of programs to reduce occupational stress may improve arterial stiffness.

Abbreviations: EDS, excessive daytime sleepiness; ESS, Epworth Sleepiness Score; HR, Heart rate; HRV, Heart rate variability; ODI, Oxygen Desaturation Index; PA, physical activity; PSQI, Pittsburgh Sleep Quality Index; RBANS; Repeatable Battery for the Assessment of Neuropsychological Status; REM, Rapid eye movement; SDB, Sleep Disordered breathing; SE, sleep efficiency; SFC, Sam-Perelli Fatigue Scale; SOL, Sleep onset latency; SQ, Sleep quality; TIB, Time in Bed; TST, Total Sleep Time; WASO, Wake after sleep onset.

psychomotor vigilance task performance, which measures reaction time to a visual stimulus [10,37,54,56,59]. All aforementioned studies concluded that poorer measures of sleep impaired cognitive performance according to lower psychomotor vigilance task scores [10,37,54,56,59]. Symptoms of other cognitive measures, such as mental fatigue [10,54] and mental alertness [54], were also worsened as a result of poor sleep hygiene.

3.6. Physiological and health measures

The included studies reported the acute effect of sleep on a variety of physiological measures including: heart rate [44,57], heart rate variability [53,57], acute inflammatory responses [43], and cortisol levels

[44]. Takeyama et al. [57] found that sleep quality, resting heart rate, and heart rate variability were adversely affected by firefighter shift schedules. Similarly, Jeklin et al. found a negative association between heart rate variability with sleepiness and fatigue [53]. Wolkow et al. found no effect of acute sleep restriction on heart rate, but reported a significant acute increase in cortisol levels [44] and inflammatory markers [43]. Studies by Vincent et al. [36,46] found no difference in heart rate or core temperature due to sleep restriction during multi-day simulated firefighting conditions.

Measures of chronic mental and physical health and were reported in several studies. In the study with the largest sample included in this review, Yook et al. [55] compared the differences in each of the 7 com-

Table 4
Newcastle-Ottawa scale assessment of study quality.

Quality assessment criteria	Acceptable (*)	Cviri (2017)	Ferguson (2016)	Haddock (2013)	Jay (2016)	Jeklin (2020)	McGillis (2017)	Stout (2020)
Selection								
Representativeness of exposed cohort?	Representativeness of the exposed cohort	*	*	*	*	*	*	*
Selection of the non-exposed cohort?	Drawn from same community as exposed cohort	*	*	*	*	*	*	*
Ascertainment of exposure?	Secured records, Structured interview	*	*	~	*	*	*	*
Demonstration that outcome of interest was not present at start of study?	Demonstration that outcome of interest was not present at start of study	*	*	*	*	*	*	*
Comparability								
Study controls for age/sex?	Yes	*	*	*	*	*	*	*
Study controls for other factors?	Environment and Schedule	*	*	*	*	*	~	*
Outcome								
Assessment of outcome?	Record linkage	*	*	*	*	*	*	*
Was follow-up long enough for outcome to occur?	Yes	*	*	*	*	*	*	*
Adequacy of follow-up of cohorts?	Complete follow-up, or subjects lost to follow-up unlikely to introduce bias	*	*	*	*	*	*	*
Overall Quality Score (Maximum=9)		9	9	8	9	9	8	9
Quality assessment criteria	Acceptable (*)	Takeyama (2005)	Vincent (2015)	Vincent (2016)	Vincent (2018)	Wolkow (2015)	Wolkow (2016)	Yook (2019)
Selection								
Representativeness of exposed cohort?	Representativeness of the exposed cohort	*	*	*	*	*	*	*
Selection of the non-exposed cohort?	Drawn from same community as exposed cohort	*	*	*	*	*	*	*
Ascertainment of exposure?	Secured records, Structured interview	*	*	*	*	*	*	*
Demonstration that outcome of interest was not present at start of study?	Demonstration that outcome of interest was not present at start of study	*	*	*	*	*	*	*
Comparability								
Study controls for age/sex?	Yes	*	*	*	*	*	*	*
Study controls for other factors?	Environment and Schedule	~	~	*	*	*	*	~
Outcome								
Assessment of outcome?	Record linkage	*	*	*	*	*	*	*
Was follow-up long enough for outcome to occur?	Yes	*	*	*	*	*	*	*
Adequacy of follow-up of cohorts?	Complete follow-up, or subjects lost to follow-up unlikely to introduce bias	*	*	*	*	*	*	*
Overall Quality Score (Maximum=9)		8	8	9	9	9	9	8

Note: Each asterisk represents if individual criterion within the subsection was fulfilled.

ponents (subjective sleep quality, latency, duration, efficiency, disturbances, medication, and daytime dysfunction) and total scores on the Pittsburgh Sleep Quality Index by low, medium and high occupational stress groups. For all sleep measures the low stress group were significantly better than the high stress group. Higher rates of depression were associated with excessive daytime sleepiness, as reported by Haddock et al. [35] However, the firefighters in the study by Stout et al. [59] reported few symptoms of anxiety and depression; thus, the conclusion was that poor sleep did not impair mental health in their sample.

Studies examining sleep's influence on physical activity during shifts reported mixed findings [39,45,46]. One study reported limited to no influence of sleep on daily physical activity,³⁸ while another reported that physical activity is not a significant covariate of sleep architecture or quantity.⁴⁴ Vincent et al. (2015) found that sleep restriction resulted in less physical activity during a multi-day simulation [46].

4. Discussion

4.1. Main findings

The purpose of the current systematic review was to synthesize the current literature related to sleep and the occupational performance and health of firefighters. Overall the current literature indicates that poor sleep negatively effects acute cognitive performance and measures of long-term health. Interestingly, physical task performance does not appear to be affected by acute sleep restriction, but the literature in this area was very limited [36,46]. For general effects of sleep deprivation and restriction on human and athletic performance, not specific to firefighters, we refer readers to several prior reviews [1,60–65]. Lastly, we provide recommendations to address the consequences of poor sleep in firefighter populations.

4.2. Physical task performance

Due to difficulty in measuring a firefighter's ability to perform physical tasks in the field [41], simulated firefighting events were commonly examined with sleep restriction of 4 h per day over multiple days [37,43–46,56]. In 2015, Vincent et al. [46] found that sleep restriction did not impair physical occupational work circuits performed at various times over three days. Of note, the control group increased performance by approximately 10% on the work circuit, but the sleep restricted group did not improve. Individuals typically improve physical task performance with familiarization (i.e., practice) [66], but the effect of familiarization may have been impaired by reduced motor learning capabilities in the sleep restricted group [67].

General literature, not specific to firefighters, has demonstrated conflicting evidence regarding the effect of restricted sleep on physical performance [1,60]. In a meta-analysis by Pilcher and Huffcutt [1] physical performance capabilities were reduced by less than 5 h of sleep in a 24 hour period. Interestingly, acute sleep deprivation was more negatively impactful than long term sleep deprivation [1]. More recently, Fullagar et al. (2015) reviewed 205 studies which investigated both total and partial sleep deprivation on exercise performance [60]. They presented mixed results regarding partial sleep restriction with many studies reporting no decline in aerobic or anaerobic performance capabilities [60]. Yet, poor sleep quantity or quality was found to cause autonomic nervous system imbalance, which ultimately results in symptoms of overtraining [68]. According to the widely accepted Selye's General Adaptation Syndrom, if progressive overloading is not properly managed (such as with adequate recovery through sleep) individuals may reach a state of non-functional overreaching or overtraining [69–71].

A narrative review by Grandou and colleagues, involving tactical populations that are more closely related to firefighters (i.e., military personnel), suggested that inadequate sleep impairs strength, endurance, aerobic and anaerobic capabilities [61]. An interesting finding was that sleep restriction appears to lead to decrements in upper body

more than lower body performance in military populations. Grandou et al. mentioned confounding factors (e.g., intraindividual variability, chronic sleep debt, motivation, and nutrition) to create difficulty in drawing meaningful conclusions pertaining to the effect of sleep restriction on physical performance in military populations [61]. It is likely that similar issues of confounding variables are present when assessing the effects of sleep on firefighter's physical performance capabilities. Further, the two studies included in the current review investigated wildland firefighters [36,46], bringing to question if these results would be similar in urban firefighters.

4.3. Cognitive performance

Five studies found a reduction in cognitive functioning as a result of poor sleep hygiene [10,35,37,56,59]. The findings related to cognitive functioning were not surprising based on prior literature in other populations [2,3,60,61]. Although sleep deprivation, partial or total, has also been shown to impair attention, decision making, short-term and long-term memory [2], more research is necessary to expand on the various cognitive functions impacted by sleep in firefighters [41].

The need for firefighters to react to unpredictable situations, navigate unfamiliar environments, make rapid decisions, operate heavy equipment and vehicles, while sleep restricted, increases the potential for serious harm to occur if cognitive abilities are impaired [16,19,73]. Individuals from other health care occupations who have extended shift schedules (>8 h) have experienced reduced vigilance on the job, increased risk of suffering an occupational injury, and a greater chance of making a medical error [73]. Additionally, in health care providers, shifts 24+ h have been associated with increased odds of experiencing a motor vehicle crash on the drive home from work and making serious medical errors [73]. Furthermore, when caring for patients, slower reaction times can delay appropriate care and increase fatigue related errors that result in fatality [74]. Thus, it is evident that poor sleep hygiene poses a serious risk to firefighters and the public due to compromised cognitive functioning [75]. However, addressing this issue may be very complicated as there are many interindividual differences in cognitive impairment from sleep loss [76], due to factors such as personality traits and chronotype [62,76,77]. Therefore, a multifaceted approach may be required that includes shorter shifts, sleep education and monitoring of sleep-related fatigue via wearable sensors.

4.4. Overall health

According to the current review, poor sleep can alter inflammatory and heart rate variability responses as well as cytokine and cortisol levels which negatively affect various physiological systems (e.g., cardiovascular, immune, nervous, musculoskeletal, respiratory) [68,78]. For example, poor sleep hygiene is associated with increased risk of cardiovascular disease (CVD) and mortality [79–81], which are particularly prevalent in firefighters [82,83]. The influence of sleep on CVD risk may be mediated by elevated cortisol levels [84], which may occur in response to sleep restriction during 3 day firefighter simulations [44] and increase CVD risk through elevated plaque scores and atherosclerosis of the carotid artery [85,86]. Additionally, Wolkow et al. [43] found increased levels of inflammatory markers (i.e., interleukin-4 and interleukin-6) due to 2 nights of sleep restriction during 3 day firefighting simulations. The cytokines respond to support the immune system in the presence of harmful internal disturbances [87,88]. However, prolonged elevations of inflammatory responses are associated with increased risk of CVD [89] and impaired cognitive functioning [88]. Collectively, the inflammatory and stress responses from restricted sleep may have detrimental chronic effects on the health and performance of firefighters. Thus, these may be candidates for biomarkers to monitor in future research.

In terms of the impact of sleep restriction on measures of cardiovascular and respiratory functioning (i.e., maximum oxygen uptake

(VO₂max)), little to no research exists. Yook et al. categorized firefighters into low ($\bar{x} > 30$), medium ($\bar{x} > 40$) and high ($\bar{x} \geq 40$) occupational stress groups using the Korean Occupational Stress scale and assessed sleep with the Pittsburgh Sleep Quality Index (PSQI) [55]. Nearly all PSQI components and overall sleep quality, as well as VO₂max values, were significantly lower in the high stress group compared to the low stress group. An intervention by von Heimburg et al. reported firefighters with greater absolute VO₂max leads to improved occupational performance compared to firefighters with lower cardiorespiratory fitness [90]. Due to firefighter occupational tasks being absolute in nature (i.e. same loads moved regardless of body size) these findings suggest that firefighters with greater cardiorespiratory fitness will perform better in simulated and emergency situations.

Feelings of daytime sleepiness are commonly associated with poor mental health [91,92]. Poor sleep hygiene has significantly large negative effects on feelings of excessive daytime sleepiness [93], which has also shown to be strongly associated with serious mental health consequences (i.e. mood, stress levels, exhaustion) in firefighters [16,17]. For example, Haddock et al. reported that firefighters with excessive daytime sleepiness showed significantly higher rates of depressive symptoms while on duty and off duty [35]. The effect of long work hours and restricted sleep on depression symptoms may also lead to long term physical health consequences, such as increased CVD risk [94,95]. Thus, the role that sleep plays in mediating the mental health of firefighters should be further investigated, as mental health related issues are already prevalent in firefighter populations due to the high occupational stressors [96].

Few studies have reported on associations between poor sleep and musculoskeletal injury rates. Haddock et al. [35] found that firefighters who reported excessive daytime sleepiness (EDS) on duty had higher injury rates than firefighters without on duty EDS; however, the results were not statistically significant. Studies of other occupations have reported the substantial impact that poor sleep can have on increasing injury rates in various occupations [64] and athletic populations [97]. Most notably the meta-analysis by Uehli and colleagues included 27 studies with 268,332 participants and concluded a 1.62 times greater risk of injury in workers with sleep problems and that 13% of workplace injuries could be attributed to sleep problems [64]. Collectively, we presume that poor sleep hygiene is a primary contributing factor to firefighter occupational injuries and that improving sleep hygiene may increase occupational performance and overall health and resiliency among firefighters.

4.5. Physical activity

Literature from the current systematic review found sleep restriction to either decrease physical activity [46] or have no effect [38,45]. A decline in physical activity, on or off-duty, might suggest that a firefighter is experiencing fatigue and could serve as an early indicator of their occupational preparedness. Since emergency responders must maintain an adequate state of preparedness [99–101], their daily physical activity may be monitored to inform current states of overall health [102], fatigue, and energy [103]. Low levels of energy associated with fatigue have been related to increased risk of sleep apnea [104], heart disease [105], depression [106], and negative well-being outcomes [107]. Furthermore, decreased physical activity during leisure time has been associated with low levels of energy and increased fatigue which can place a responder in a decreased state of preparedness [108,109]. For these aforementioned reasons physical activity may be a viable surrogate measure of occupational preparedness, as well as the health and career longevity of firefighters.

4.6. Factors influencing sleep

A framework of influential operational and environmental factors for wildland firefighters' sleep hygiene was presented by Vincent and col-

leagues [41]. Operational factors were described as the shift schedules (i.e. start time and the shift length) [17,20,110] while environmental factors were described as sleeping location [110] and environmental stimuli (i.e. smoke, noise, heat) [111]. Despite the prior work solely including wildland firefighters, we believe these factors apply to majority of firefighters. Specifically, shift schedules appear to be problematic in regard to obtaining adequate sleep across many occupations.

In the United States alone, over 100 different firefighting shifts have been reported by the National Institute for Occupational Safety and Health [112]. Worldwide the most commonly used shift schedules are ≥ 24 h [9]. However, over 70% of firefighters who worked >24 h shifts had poor sleep quality, with longer shifts corresponding with worsened circadian rhythm disruptions [9]. Elliot and Kuehl [19], reported that shifts lasting longer than 10 to 18 h lead to errors in performing tasks that require vigilance and alertness. Haddock and colleagues found that firefighters who reported EDS of 20.4% and 12.2% when working 48-h and 24-h shifts, respectively [35]. With the focus of our current paper on unique aspects of sleep on firefighter health and occupational performance we will recommend several prominent reviews of the general effects of shiftwork on sleep to readers [114,115].

Sleeping location and environmental stimuli have substantial impacts on sleep of firefighters working in both austere and urban environments [110,116–118]. As mentioned by Vincent and colleagues, the ability of wildland firefighters to sleep in remote locations is reduced as the distance from urban settings increases [41]. Firefighters allowed to sleep in hotels get an average of 6.2 h of sleep compared to 5.2 h in a tent [41]. Although not common and can be dependent on the situation, firefighters sleeping in vehicles during operations may only obtain 4.5 h of sleep [41]. Thus, sleeping location has a substantial impact on firefighters' sleep hygiene. Furthermore, environmental factors such as heat [45], noise [111], and light [116] have been established as factors that can negatively impact sleep quality [119–121]. Understanding the influence of location and environment on sleep hygiene is an important step to further policy development and be incorporated into firefighter sleep education programs [117].

4.7. Recommended future research directions

The current review supports that more research is needed to measure the acute responses (i.e. reaction time, sleepiness, decision making capabilities, physical capabilities under stress) due to total versus partial sleep restriction over multiple days. Physical occupational tasks should be investigated to assess the concomitant effect of sleep restriction on cognitive and physical capabilities (i.e., physical tasks with cognitive components of reaction times and decision making). Unfortunately, several nuances apply when attempting to identify occupational performance capabilities and risks in real world scenarios. Investigating simulated firefighter events is an appropriate start, but considering the lower occupational and environmental stressors, simulated events may not accurately depict the psychophysiological responses of firefighters during an emergent real-life event. Furthermore, for studies examining physical performance we caution future researchers to carefully consider confounding factors described by Grandou et al. in research designs to maximize the quality of future work in this area [61].

With the advent of wearable technology and athlete management systems to track an assortment of physiological measures, it seems prudent that fire departments consider adopting systems similar to many athletic teams and other tactical populations [122–124]. Existing frameworks used to monitor external and internal physiological loads of athletes [125–127] could be adapted to provide relevant measures of readiness, including sleep and physical activity, of firefighters within a department. For example, physical activity is easily assessed with wearables and may be a viable surrogate measure of occupational preparedness, as well as the health and career longevity of a firefighter. Although a number of studies have begun to examine potential benefits of wearable devices for monitoring physiological loads experienced during fire-

fighting events [47,128,129], an approach of utilizing continuous monitoring would be advised. The application of monitoring systems may stem from general recommendations for tactical populations, such as a recent narrative review on applying heart rate variability monitoring in tactical personnel [68]. Thus, alike the conclusions from Vincent et al. in 2018 [41], we conclude that more research is warranted in regard to the effects of sleep on firefighter's physical performance capabilities.

4.8. Call for action and practical recommendations

Since the 2007 report by the International Association of Fire Chiefs and the United States Fire Administration [19] subsequent literature has only provided more support to the negative consequences of poor sleep on firefighter performance and well-being. The concern is that many departments have not taken action to address this issue. Although each fire department may have unique constraints and a one-size fits all approach is not appropriate, we urge each fire department to take some step to support better sleep hygiene and strongly consider the consequences of not taking action. We urge fire departments to explore existing health and wellness models [130] that address poor sleep in order to optimize firefighter preparedness. Given the known consequences of poor sleep the costs of not taking action is simply too great to continue to simply maintain status quo.

To maintain preparedness, organizations within the US Armed Forces have researched shift schedules and concluded that soldiers should not exceed 8 consecutive work hours and should receive at least 8 h of sleep every 24 hour period [131]. Although work shifts of 8 h may be ideal from an occupational preparedness perspective it is difficult for fire stations to function on these work schedules and as a result, other approaches to promote healthy sleep hygiene are encouraged.

The immediate issue of poor sleep hygiene for firefighters is the increased mental and physical fatigue. There are many ways to monitor an individual's state of fatigue, be it wearable sensors or self-perceived questionnaires. The use of questionnaires and wearable sensors allow 24-hour monitoring of physiological measures, including sleep, and has been shown to effectively improve athletic performances [132]. Additionally wearables have already shown promise in the firefighting environment [47]. Of course there will be situations when it is necessary to keep a fatigued firefighter on duty and countermeasures will need to be implemented. Some fatigue related countermeasures such as increased communications or supervision [116], mandatory recovery time [133], or caffeine administration [134,135] may be viable options to maintain operation effectiveness and safety for everyone for short periods of time. These short-term countermeasures should only be implemented when absolutely necessary and not a part of routine operations. Another option to assess fatigue that can be considered is the use of occupational safety performance assessment technology can quickly screen an individual to see if a firefighter is in a potentially dangerous state to begin or continue a shift schedule [136].

There is a growing body of literature supporting sleep interventions to improve sleep quality in firefighters [117,137,138]. Sleep interventions typically consist of sleep education and screening for sleep disorders. In 2016, Sullivan and colleagues found that firefighters who completed both sleep education and screening for sleep disorders reported 46% fewer disability days [117]. Another finding from the study was firefighters who attended education sessions were 24% less likely to file at least one injury report than those who did not attend. Barger et al. conducted a similar study and found that when the sleep education program delivered by a sleep expert, as opposed to a train-the-trainer or online program, was more effective in educating and screening firefighters for sleep disorders [137]. Thus, we recommend that all firefighters are educated on the dangers of poor sleep on a firefighter performance and health as part of standard training [117]. Additionally, screening firefighters for sleep related disorders should be a part of routine evaluations to ensure firefighters are not dealing with an underlying condition

that can prevent them from obtaining good quality of sleep [16,117,139] and lower their chance of vehicular accidents [140].

4.9. Conclusion

The current evidence indicates that firefighters experiencing poor sleep are at risk for worsened cognitive functioning and negative physical and mental health outcomes. Performances of firefighter's physical driven occupational tasks do not appear to be impacted by acute partial sleep deprivation; however, there is currently limited research on the matter. Since poor sleep is associated with a decline in a broad range of health measures, it is logical that over a longer period of time chronic poor sleep will ultimately have a detrimental effect on physical performance. Future studies should investigate how physical capabilities and overall health of firefighters are impacted longitudinally by poor sleep. There are several strategies that leadership should consider, such as modifying shift schedules, implementing interventions to improve sleep, conducting planned and event based sleep screenings, and utilizing wearable devices to monitor sleep, heart rate metrics, and/or physical activity.

Declaration of Competing Interest

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