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► To cite this version:

Alain Gros Lambert, Philémon Marcel-Millet, Philippe Gimenez, Sidney Grosprêtre, Gilles Ravier. Psychophysiological responses of firefighters to day and night rescue interventions. *Applied Ergonomics*, 2021, 95, pp.103457. 10.1016/j.apergo.2021.103457 . hal-03381875

HAL Id: hal-03381875

<https://hal.science/hal-03381875>

Submitted on 24 May 2023

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Title: Psychophysiological responses of firefighters to day and night rescue interventions

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Abstract

This study aimed 1) to assess the psychophysiological responses throughout a rescue intervention performed during the day and at night and 2) to determine if a vibrating alarm influences these psychophysiological responses at night.

Sixteen male firefighters completed a simulated intervention under three different conditions: 1) during the day with a sound alarm signal (Day_{SA}), 2) during the night with a sound alarm signal (Night_{SA}), 3) during the night with a vibrating alarm signal (Night_{VA}). Cardiovascular and psychological stress were recorded throughout the interventions.

During the alarm signal, HR reactivity was greater in Night_{SA} than in Day_{SA} ($p < 0.01$). Parasympathetic reactivation and self-confidence were significantly lower in Night_{SA} than in Day_{SA} ($p < 0.05$). **HR reactivity was decreased in Night_{VA} in comparison to Night_{SA} ($p < 0.05$).**

Overall, the rescue intervention had a greater impact on the psychophysiological variables during the night than during the day, and the type of alarm had a minor effect.

Key Words: firefighting activity; autonomic nervous system; heart rate variability

Abbreviations:

BP	Blood pressure
CSAI-2	Competitive state anxiety inventory-2 questionnaire
CT	Completion time
HF	High frequency
HR	Heart rate
HRR	Heart rate recovery
HRV	Heart rate variability
HR _{max}	Maximal heart rate
SD	Standard deviation
SD1	Instantaneous beat-to-beat R-R interval
SSS	Stanford sleepiness scale
RPE	Rating of perceived exertion
RMSSD	Root mean square of successive differences of R-R intervals

1. Introduction

Firefighting is a ~~very~~ demanding occupational ~~activity that leads to a~~ ~~with~~ high level of psychophysiological stress during rescue interventions (Williams-Bell et al. 2009; Horn et al. 2011, 2019; Smith et al. 2016; Windisch et al. 2017). It is important for firefighters to be physically fit in order to enhance their firefighting performance, which can be quantified by the time required to carry out their duties (Williams-Bell et al. 2009), as well as by the associated physiological responses (Windisch et al. 2017). In France, firefighters work a 24-hour shift, so they have to maintain a high level of performance regardless of the time of day or night. However, to date, firefighters' performance and physiological stress in response to interventions have only been studied during the day (Williams-Bell et al. 2009; Horn et al. 2011, 2019; Windisch et al. 2017) except for the acute response to the alarm signal, which has been compared between day and night conditions (Hall et al. 2016). The authors showed that the increase in heart rate (HR) was similar during the day and night, whereas the increase in cortisol was higher at night than during the day. Several studies conducted with healthy subjects have shown that physical performance is better late in the afternoon than in the early morning (Baxter and Reilly 1983; Thun et al. 2015). However, these results appear to be equivocal, and other studies revealed no effect of circadian rhythm on physical performance (Reilly and Brooks 1982; Deschenes et al. 1998). Moreover, at rest, several physiological functions, such as rectal temperature, HR, plasma lactates, blood pressure (BP) ~~or~~ and cortisol levels, follow a circadian rhythmicity (Reilly and Brooks 1982; Deschenes et al. 1998), which can also be found during or after exercise (Harma et al. 1982). These results are controversial since other studies did not show any circadian variations in HR responses ~~at~~ ~~with~~ exercise (Reilly and Brooks 1982; Deschenes et al. 1998). Consequently, the general picture of the circadian modulations of performance and physiological variables is unclear. It seems that this variation should be highly dependent upon the type of exercise and the characteristics of the participants. Moreover, beyond the circadian variations, the state (awake / asleep) in which the firefighter is in, at the time of the intervention, can influence his or her psychophysiological ~~responses~~. Indeed, HRV and HR seem to be largely under a sleep-wake-dependent process (Viola et al. 2002). Therefore, it would be important for the safety and security of firefighters to measure if the performance of firefighters is modulated by the moment of the intervention (daytime vs night-time).

Moreover, the psychophysiological stress resulting from firefighting activities depends on the interaction of three different phases during an intervention. The first phase, the alarm mobilisation phase, corresponds to the alarm signal followed by the moment when firefighters change into their protective clothing before leaving the fire station. This phase leads to physiological stress with an increase of HR from 20 to 66 beats·min⁻¹ in a short period of time (Kuorinka and Korhonen 1981; Karlsson et al. 2011; Hall et al. 2016), and an increase in salivary cortisol concentrations (Hall et al. 2016). The second phase, the fire suppression phase, corresponds to the phase of firefighting activities, such as forcible entry, search and rescue operations or extinguishing a fire (Kales et al. 2003). During this phase, firefighters engage in intense physical activity in psychologically stressful situations with high temperatures. This leads to high, and sometimes maximal, HR, and to an increase in BP, body temperature and psychological stress (Barr et al. 2010; Williams-Bell et al. 2010; Horn et al. 2011; Windisch et al. 2017; Marcel-Millet et al. 2018; Wilkinson et al. 2020). The third phase, the alarm return phase, corresponds to the several hours following a fire suppression. During this period, the psychophysiological stress generated by the intervention remains, and it can sometimes take several hours for the physiological parameters to return to

initial levels. After simulated firefighting activities, core temperature continues to increase for many minutes (Selkirk et al. 2004; Horn et al. 2011), and the HR returns to baseline values only after about 80 minutes (Horn et al. 2011). Furthermore, a significant acute parasympathetic perturbation has been observed after simulated firefighting activities (Marcel-Millet et al. 2018). Indeed, in this study, ~~we observed~~ a greater vagal depression ~~was observed~~ after a simulated emergency than after an incremental running test performed until exhaustion.

The amount of stress during ~~a fire the interventions~~ can represent major issues for firefighters on two levels. First, for firefighters with underlying cardiovascular disease, a significant amount of stress can induce pathophysiological changes causing a risk of death (Smith et al. 2016; Kales and Smith 2017). Second, regular exposure to a source of stress could contribute to the long-term development of cardiovascular disease (Stephoe and Kivimäki 2012). Thus, despite a high level of exposure to traumatic risks (Kong et al. 2013), sudden cardiac events are the leading cause of line-of-duty death for firefighters in the United States (Kales et al. 2007; Smith et al. 2016). Consequently, the comparison of a day and night intervention would determine whether or not firefighters' performance and psychophysiological stress are affected by the time period in which ~~the intervention~~ occurs, considering that an increase in cardiovascular stress is associated with adverse outcomes for the health of firefighters (Smith et al. 2016; Kales and Smith 2017).

Finally, the sudden increase in HR and BP in response to the emergency alarm increases the risk of death among firefighters (Kales et al. 2003, 2007). A previous study showed that in comparison to a classical emergency alarm, a gentle awakening carried out by an experimenter mitigated the increase in HR (Hall et al. 2016). Usually, the alarm signal is a sound of at least 85 db(A) emitted by a transmitter carried by the firefighter. Recently, the Regional Fire and Rescue Service offered to some firefighters a modified transmitter that starts by vibrating for 30 seconds, before emitting a sound signal if the transmitter is not turned off. The objective of this device is to reduce the stress of the firefighters during the alarm. Therefore, it is important to measure its effectiveness in workplace ~~ecological conditions~~, to guide firefighters in their choice of alarms.

Consequently, the present field study aimed to: (1) compare the daytime and night-time physiological and psychological responses of structural firefighters to a simulated emergency; (2) compare the physiological and psychological responses of structural firefighters to a sound alarm and a vibration alarm, at night. It was hypothesised that the night intervention would exhibit higher physiological response than the day intervention, and that this higher response could be attenuated by a less noisy alarm.

2. Materials and methods

2.1 Participants

Sixteen male firefighters participated in this study (Table 1). All the participants had been medically screened by the local firefighter's healthcare institution, and each had received medical clearance to engage in firefighting activities. Prior to testing, all the participants gave their voluntary written informed consent, which indicated the purpose, the benefits and the risks of the investigation and the right to withdraw from participation at any time. This study was conducted in accordance with the recommendations of the 1964 Declaration of Helsinki and its later amendments. The research design was examined and approved by the medical service and the Institutional Review Board of the Regional Fire and Rescue Service.

Table 1: Characteristics of the participants

Age	Height	Weight	Body mass index	Estimated $\dot{V}O_{2max}$	Work experience
36.1 ± 5.8 years	175.3 ± 6.1 cm	73.6 ± 10.1 kg	23.8 ± 1.7 kg/m ²	55.8 ± 3.6 ml·min ⁻¹ ·kg ⁻¹	18.6 ± 5.9 years

2.2 Experimental design

The study was conducted at the participants' workplace, and the rescue intervention was part of their occupational activity. The experimental exercises were part of the firefighters' regular training exercises. Prior to the experimental sessions, during a familiarisation session, the procedures were **thoroughly** explained, and the participants tested the connected suit and the psychological questionnaires used in the experimental sessions. The connected suit used in this study was that of the Hexoskin brand (Hexoskin® Carré Technologies Inc., Montreal, Canada). Next, the participants completed the Intermittent Fitness Test (Buchheit 2008) to determine their individual HR peak (HR_{max}). The $\dot{V}O_{2max}$ was estimated based upon the participant's final running speed using the following formula (Buchheit 2010) : $\dot{V}O_{2max}$ (ml·min⁻¹·kg⁻¹) = $28.3 - (2.15 \times G) - (0.741 \times A) - (0.0357 \times W) + (0.0586 \times A \times V_{IFT}) + (1.03 \times V_{IFT})$ where: V_{IFT} is the final running speed, G is gender (male = 1), A is age (in years) and W is weight (in kilograms). Then, all the participants performed the three experimental conditions in a randomised order, interspersed by a ~~minimal~~ **minimum** of 3 days and a maximum of 14 days. The firefighters completed the same simulated rescue intervention (Figure 1) under three different conditions: 1) during the day, in the morning, with a sound alarm signal (Days_{SA}), 2) during the night with a sound alarm signal (Nights_{SA}) and 3) during the night with a vibrating alarm signal (Night_{VA}). The simulated rescue intervention consisted of 5 tasks, without downtime: (a) *Hoses*: The participants carried two hoses (7 kg each) over flat ground for a distance of over 100 m; (b) *Obstacles course*: After setting down the hoses, the participants completed a 50-meter course that required them to crawl under obstacles; (c) *Tower*: The participants grabbed their hoses again, and dropped them on the 4th floor of a tower; (d) *Mannequin*: The participants used a strap to carry a 60 kg mannequin down one floor and then up one floor; (e) *Hoses*: Finally, the participants hoisted their hoses again before going down the 4 floors of the tower and returning to the starting point. During each session, the participants were asked to perform the simulated rescue intervention as quickly as possible; they were given verbal encouragement throughout the test.

For the Days_{SA} condition, the participants completed a 10-minute sitting rest period at 08:00 h in a quiet room at ambient temperature (~20°C) in order to perform the resting measurements. Then, at 08:30 h, they went to a bedroom that was assigned to them for the duration of the study. In the bedroom, they rested without sleeping, lying down wearing the same attire they wear when sleeping at night in the fire station. The participants were informed that they might hear an alarm for the simulated rescue intervention at any time of the morning. At 09:00 h, the alarm signal was triggered. It was issued by a transmitter assigned to the firefighter and usually used for real interventions. The alarm was placed on a table next to the bed, at a distance of about 1 meter from the firefighter. The sound of the signal was about 85 db(A). Upon hearing the signal, the firefighters had to get dressed and go to the locker room as quickly as possible. The time between the triggering of the alarm and the arrival in the locker room corresponds to the alarm mobilisation phase. Once in the locker room, the pre-

simulated intervention measures were carried out for 5 minutes, and the participants were equipped with the protective equipment for the simulated rescue intervention. The personal protective equipment consisted of a helmet, gloves, a bunker coat and pants, boots and a self-contained breathing apparatus with an air cylinder and facial mask, for a total weight of approximately 22 kg. For breathing at a standard rate of 40 L·min⁻¹, the SCBA cylinder used in the study can provide 45 minutes of air. Under their personal protective equipment, the firefighters wore the standard clothing provided by the service, namely long pants and t-shirts. Once equipped and ready, all the participants performed the simulated rescue intervention as quickly as possible. When the firefighters finished the simulated rescue intervention, they had 1 minute to remove their personal protective equipment (SCBA, helmet, jacket) before completing a 10-minute resting period in a seated position in a quiet room at ambient temperature (~20°C). For the Night_{SA} and the Night_{VA} conditions, the resting measurements were completed at 22:00 h in the same room as in the Day_{SA} condition. Then, the participants went into the same bedroom that was used for the daytime simulation, between 22:30 h and 23:30 h, depending on their habits. They were informed that they might hear an alarm for the simulated rescue intervention at any time during the night. The alarm signal was triggered approximately 2 hours after the bedtime that was indicated by the firefighter, between 00:30 h and 01:30 h. Particular care was taken to ensure that the participants were sleeping deeply when the alarm sounded. We asked them in what state they were at the time of the alarm (sleeping, sleepy, awake) and if they were awake or sleepy the experiment was postponed for a different night. The same transmitter and the same sound were used for the Night_{SA} condition and the Day_{SA} condition. For the Night_{VA} condition, the transmitter signal was modified so that it would only vibrate for 30 seconds. At the end of the 30 seconds, if the firefighter did not turn off the transmitter, a sound signal was added to the vibrations. Then, the **whole** protocol during the Night_{VA} condition **was were** the same as that used in the Night_{SA} condition (Figure 1). Again, we have ensured that the participants were woken only by the vibrations. If it **was is** the sound that woke them up, then the experiment was postponed for a different night.

The three experimental conditions were performed in a randomised order. For the three conditions, everything was done to allow for maximum uncertainty, as in real conditions. The study was conducted at the participants' workplace, it was part of their occupational activity and they could be called either for the simulated rescue intervention or for real interventions. In addition, several nights were recorded with the Hexoskin® suit, during which they were warned that they could be awakened, without us actually doing so. The participants were also asked to abstain from consuming caffeine 3 hours before testing and from engaging in high intensity exercise and consuming alcohol 24 hours before the tests. All the participants were familiar with the simulated rescue intervention and the fitness test because both had been part of their occupational skills training and the regular monitoring of their physical abilities. Indeed, once a year, the firefighters of the regional fire service perform physical tests: the incremental running test and also measurements of muscular endurance, flexibility, etc. These tests are then reviewed by the hierarchy and the health service. Finally, the simulated intervention is carried out regularly by the firefighters (i.e. several times a year), as part of their training exercises.

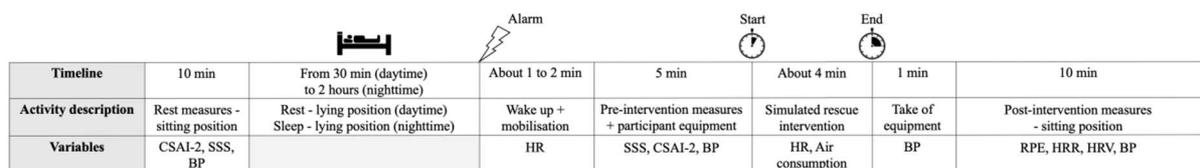


Figure 1. Overview of the experimental design. CSAI-2: Competitive State Anxiety Inventory - 2; SSS:

Stanford Sleepiness Scale; RPE: rating of perceived exertion; HR: heart rate; HRR: heart rate recovery; HRV: heart rate variability; BP: blood pressure

2.3 Data analysis

2.3.1 Assessment of the firefighting performance

For both the alarm mobilisation phases and the simulated rescue interventions, the completion time (CT) was recorded manually using a manual chronometer. For the alarm mobilisation phase, the time trial began when the alarm was triggered; it ended when the firefighters entered the locker room. For the simulated rescue intervention, the time trial started at the beginning of the first task; it ended when the firefighter crossed the finish line. Air consumption was quantified in bars directly from the pressure recorded on the manometer of the self-contained breathing apparatus at the start and the end of the simulated rescue intervention. The accuracy of the pressure gauge was ± 5 bars.

2.3.2 Assessment of the physiological parameters

The participants were fitted with a connected suit during the three experimental conditions and during the Intermittent Fitness Test. The connected suit provided an electrocardiogram signal at a frequency of 256 Hz from three electrodes (two on the chest, one on the right supra iliac region). The data that were recorded using the Hexoskin® suit were shown to be reliable and valid under a laboratory condition (Elliot et al. 2019). Then, HR was calculated at 1 Hz, and was analysed during three distinct periods. During the alarm mobilisation phase, the pre-alarm HR corresponded to the average HR of the previous 5 seconds before the alarm signal, the peak HR was the maximal HR reached during the phase and the HR reactivity was calculated as the difference between peak HR and pre-alarm HR. For the alarm mobilisation phase, the pre-alarm HR, the peak HR and the HR reactivity were expressed in $\text{beats}\cdot\text{min}^{-1}$. Then, mean and peak HR were determined for the entire simulated rescue intervention. For the simulated rescue intervention, mean and peak HR were expressed as the percentage of the maximal HR measured during the Intermittent Fitness Test ($\% \text{HR}_{\text{max}}$). Finally, during the recovery period, HR recovery (HRR) was calculated by taking the difference between the exercise final HR and the HR at 60 seconds after the end of the exercise ($\text{HRR}_{60\text{s}}$). Thus, a short-term HR time constant, a T30 index, was determined as the negative reciprocal of the slope of the regression line for the first 30 seconds ($-1/\text{slope}$). Since for a few seconds after high intensity exercise, HR can continue to rise or plateau, we actually calculated the T30 from the 10th to the 40th seconds of recovery, as previously recommended (Peçanha et al. 2017). It has been demonstrated that the $\text{HRR}_{60\text{s}}$ and T30 indices reflect parasympathetic reactivation immediately after exercise (Peçanha et al. 2017).

HR variability (HRV) derived from the electrocardiogram signal extracted from the Hexoskin® suit was recorded 10 minutes after the simulated rescue interventions. R-R intervals were analysed both on time- and frequency-domains using Kubios software (Kubios HRV Analysis v3.0; Bio-signal Analysis and Medical Imaging Group at the Department of Applied Physics, University of Kuopio, Kuopio, Finland), and the signal was corrected automatically using software correction with a medium threshold of correction. After a 5-minute period of stabilisation, HRV analysis was performed for a 5-to-10-minute period, post-exercise. In the frequency domain, HRV was analysed using spectral analysis of the intervals from the fast Fourier transform. The high

frequency (HF, ms²) band, ranging between 0.15 Hz and 0.40 Hz, was selected for this study as the index to evaluate the post-exercise parasympathetic nervous system reactivation. Post-exercise vagal modulations were also assessed in the time domain by calculating the root mean square of successive differences of normal R-R interval (RMSSD, ms) and the standard deviation of instantaneous beat-to-beat R-R interval variability derived from the Poincaré Plot analysis (SD1, ms) indices.

Arterial systolic and diastolic BP were assessed via auscultation on the left upper arm while passively supporting the lower arm. In each condition, the participants' BP was assessed at the end of the resting measures, during the pre-simulated intervention measures, within the first minute of the post-simulated intervention and at the 10-minute post-simulated intervention.

2.3.3 Assessment of the psychological parameters

The firefighters' anxiety and self-confidence levels were measured using a French adaptation (Cury et al. 1999) of the Competitive State Anxiety Inventory-2 (CSAI-2) questionnaire (Martens et al. 1990). This questionnaire consists of 27 items related to feelings of cognitive anxiety, somatic anxiety and self-confidence. In each of the study conditions, all the participants completed the questionnaire during the resting measures and during the pre-simulated intervention measures. Then, sleepiness was assessed during the resting and pre-simulated intervention measures using the Stanford Sleepiness Scale (SSS) (Herscovitch and Broughton 1981). Finally, the rating of perceived exertion (RPE) was self-evaluated 10 minutes after the end of the simulated rescue intervention by using the category ratio scale.

2.4 Statistical analysis

All data were expressed as mean \pm standard-deviation (SD). The normality for data distribution and the equality of variance between the samples were checked with Shapiro-Wilk's test and Bartlett's test, respectively. Because the RMSSD and the HF indices were not normally distributed, the data were log-transformed (lnRMSSD and lnHF). The differences between the Days_{SA} and the Nights_{SA} conditions and the differences between the Nights_{SA} and the Night_{VA} conditions were analysed using pairwise *t*-tests if the data were normally distributed (for CT, air consumption, HR, T30, HRR_{60s}, lnRMSSD, lnHF and SD1) or Wilcoxon tests if the data were not normally distributed (for the psychological parameters and BP values). To account for the increased possibility of a type-I error, the Bonferroni correction was used to adjust for multiple statistical tests (VanderWeele and Mathur 2019). Friedman tests were used to analyse the BP differences between *time* measures (Resting-, Pre-, Post-1 min, post-10 min measures) and the Nemenyis procedure was used when the null hypothesis was rejected. Statistical analysis was performed using XLSTAT software 2013 (Addinsoft SARL, Paris, France). Statistical significance was set at <0.05. The magnitude of the differences was interpreting using Cohen's *d* effect-size where <0.20 is trivial, 0.20 to 0.49 is small, 0.50 to 0.79 is moderate and >0.80 is large (Cohen 1988).

3. Results

3.1 Performance and physiological parameters

The alarm was triggered at 08:32 h \pm 00:07 h for the Days_{SA} condition, at 00:50 h \pm 00:17 h for the Nights_{SA} condition and at 00:53 h \pm 00:16 h for the Night_{VA} condition.

For the three experimental conditions, the CT and HR responses for both the alarm mobilisation phase and the simulated rescue intervention are presented in Table 2. The cardiac parasympathetic indices of the acute recovery phase for the three conditions are also displayed in Table 2. All the cardiac parasympathetic indices were lower in the Night_{SA} condition in comparison to the Day_{SA} condition. HR reactivity was lower in the Day_{SA} condition in comparison to the Night_{SA} condition ($p < 0.01$) and was also lower in the Night_{VA} condition in comparison to the Night_{SA} condition ($p < 0.05$). Air consumption during the simulated intervention was not significantly different between the Day_{SA} and Night_{SA} conditions (85.6 ± 19.7 and 78.8 ± 17.2 bars, respectively) and between the Night_{SA} and Night_{VA} (77.5 ± 14.8 bars) conditions.

Table 2. Performance, HR responses and parasympathetic reactivation indices for the three experimental conditions.

Phases	Variables	Day _{SA}	Night _{SA}	Night _{VA}	Day _{SA} vs. Night _{SA}	Night _{SA} vs. Night _{VA}
					ES (± 95 CI)	ES (± 95 CI)
					<i>ES descriptor</i>	<i>ES descriptor</i>
Alarm mobilisation	CT mobilisation (s)	57.9 \pm 26.6	104.9 \pm 31.6***	114.7 \pm 27.8	1.61 (± 0.82) <i>Large</i>	0.54 (± 0.61) <i>Medium</i>
	Pre-alarm HR (beats·min ⁻¹)	58.6 \pm 8.2	50.7 \pm 4.5***	51.3 \pm 8.1	1.18 (± 0.77) <i>Large</i>	0.09 (± 0.60) <i>Trivial</i>
	Peak HR (beats·min ⁻¹)	123.7 \pm 18.4	127.9 \pm 20.3	116.1 \pm 21.7	0.22 (± 0.72) <i>Small</i>	0.57 (± 0.61) <i>Medium</i>
	HR reactivity (beats·min ⁻¹)	65.1 \pm 17.9	77.2 \pm 20.4**	64.7 \pm 19.5 #	0.63 (± 0.73) <i>Medium</i>	0.63 (± 0.61) <i>Medium</i>
Simulated intervention	CT intervention (s)	251.8 \pm 38.6	257.6 \pm 50.1	254.7 \pm 33.2	0.13 (± 0.72) <i>Trivial</i>	0.07 (± 0.60) <i>Trivial</i>
	Mean HR (% HR _{max})	86.0 \pm 4.0	85.2 \pm 4.7	84.3 \pm 4.0	0.19 (± 0.72) <i>Trivial</i>	0.21 (± 0.60) <i>Small</i>
	Peak HR (% HR _{max})	90.6 \pm 2.9	89.6 \pm 3.4	89.6 \pm 2.2	0.34 (± 0.72) <i>Small</i>	0.01 (± 0.60) <i>Trivial</i>
Acute recovery	T30 (s)	171.8 \pm 71.4	251.1 \pm 106.0*	217.3 \pm 46.7	0.88 (± 0.75) <i>Large</i>	0.41 (± 0.61) <i>Small</i>
	HRR _{60s} (beats·min ⁻¹)	38.0 \pm 12.2	31.6 \pm 8.4*	31.7 \pm 10.0	0.61 (± 0.73) <i>Medium</i>	0.01 (± 0.60) <i>Trivial</i>
	lnRMSSD (ms)	2.46 \pm 0.64	2.15 \pm 0.47*	2.34 \pm 0.47	0.56 (± 0.73) <i>Medium</i>	0.42 (± 0.61) <i>Small</i>
	SD1 (ms)	9.89 \pm 5.93	6.73 \pm 3.29*	8.07 \pm 3.07	0.66 (± 0.73) <i>Medium</i>	0.42 (± 0.61) <i>Small</i>
	lnHF (ms ²)	3.88 \pm 1.47	2.85 \pm 1.11*	3.04 \pm 1.17	0.79 (± 0.74) <i>Medium</i>	0.16 (± 0.60) <i>Trivial</i>

Mean \pm SD are displayed for Day_{SA} (day sound alarm), Night_{SA} (night sound alarm) and Night_{VA} (night vibrator alarm) conditions. CT: completion time; T30: short-term time constant; HRR_{60s}: heart rate recovery at 60 sec post-exercise; lnRMSSD: natural logarithm of the root mean square of successive differences of normal R-R intervals; lnHF: natural logarithm of high frequency power; SD1: standard deviation of instantaneous beat-to-beat R-R intervals variability derived from the Poincaré Plot analysis. *shows a significant difference vs. Day_{SA} with * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$; #shows a significant difference vs. Night_{SA} with # $p < 0.05$.

HRR after the three experimental conditions is displayed in Figure 2. No difference was found between the conditions for the HR at the end of the exercise. After 60 seconds of recovery, HR was higher in the Night_{SA} condition than in the Day_{SA} condition ($p < 0.05$).

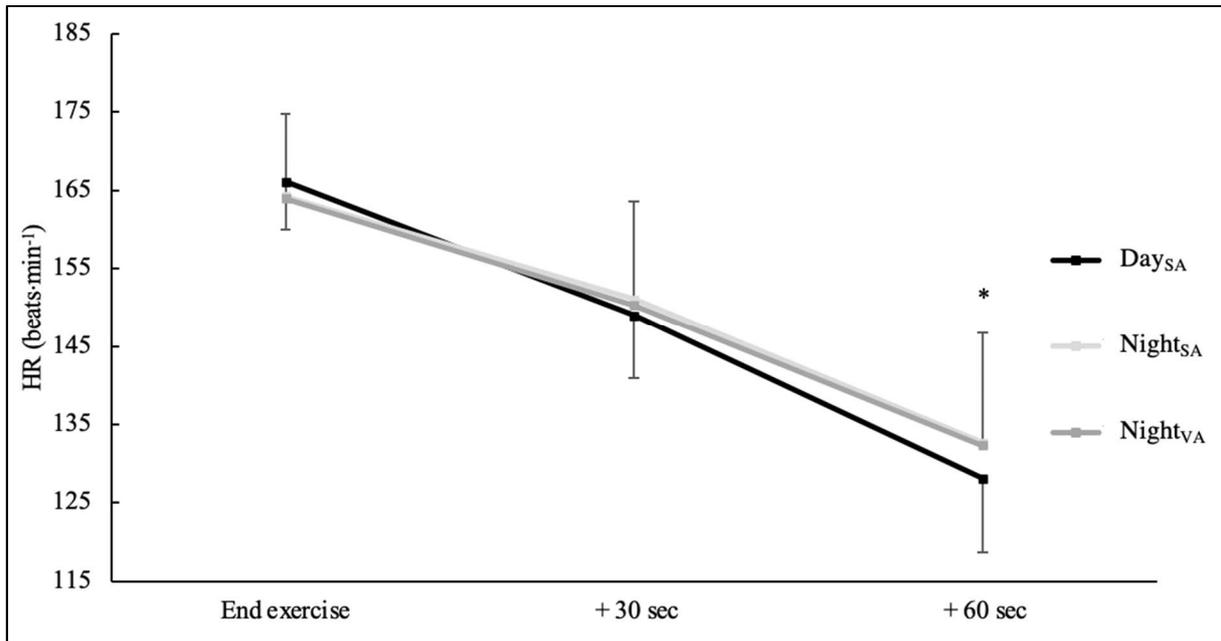


Figure 2. Heart rate (HR) recovery after the end of the exercise in the Day_{SA} (day sound alarm), Night_{SA} (night sound alarm) and Night_{VA} (night vibrator alarm) conditions. * shows a significant difference between Day_{SA} and Night_{SA} with * $p < 0.05$.

Systolic BP and diastolic BP for the three experimental conditions are presented in Figure 3. There was a significant difference between the pre- and 1-min post-simulated intervention systolic BP in comparison to resting systolic BP for both the three conditions, but no difference was found between the conditions.

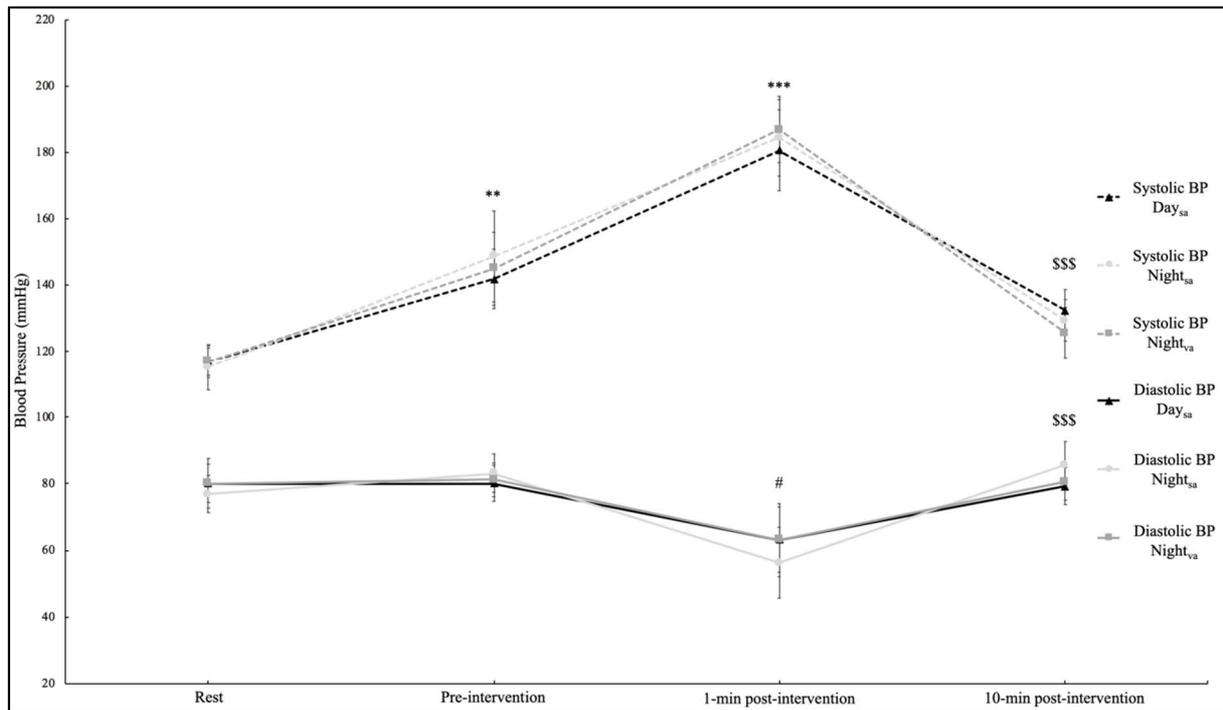


Figure 3. Changes in systolic and in diastolic blood pressure (BP) throughout the Day_{SA} (day sound alarm), Night_{SA} (night sound alarm) and Night_{VA} (night vibrator alarm) conditions. **: significant difference vs. rest ($p < 0.01$); ***: significant difference vs. rest ($p < 0.001$); #: significant difference vs. pre-intervention ($p < 0.05$); \$\$\$: significant difference vs. 1-min post-intervention ($p < 0.001$).

3.2 Psychological parameters

Post-simulated intervention RPE was not significantly different between the Day_{SA} and Night_{SA} conditions (7.4 ± 2.1 and 8.1 ± 2.2 respectively). The post-simulated intervention RPE was 8.1 ± 1.7 for the Night_{VA} condition, which was not significantly different from the Night_{SA} condition.

Differences between the resting and pre-simulated intervention values of the CSAI-2 and SSS questionnaires are presented in Table 3. The comparison of the Day_{SA} and Night_{SA} conditions revealed a higher level of pre-simulated intervention sleepiness ($p < 0.0001$) and a lower level of pre-simulated intervention self-confidence ($p < 0.01$) for the Night_{SA} condition in comparison to the Day_{SA} condition. The comparison revealed no differences between the Night_{SA} and Night_{VA} conditions.

Table 3. Evolution of the psychological parameters (sleepiness, anxiety and self-confidence) from rest to pre-simulated intervention for the Days_{SA}, Nights_{SA} and Night_{VA} conditions.

	Condition	Rest	Pre-intervention	ES (± 95 CI)	Evolution (%)	ES descriptor
SSS (on 7)	Day _{SA}	1.69 \pm 1.01	1.81 \pm 1.05	0.12 (± 0.72)	7	Trivial
	Night _{SA}	2.13 \pm 1.54	4.25 \pm 1.73 **	1.30 (± 0.78)	100	Large
	Night _{VA}	2.25 \pm 1.24	3.56 \pm 0.96 **	1.18 (± 0.77)	58	Large
CSAI-2 Somatic Anxiety (on 4)	Day _{SA}	1.21 \pm 0.27	1.64 \pm 0.47 ****	1.11 (± 0.77)	36	Large
	Night _{SA}	1.24 \pm 0.31	1.77 \pm 0.60 ****	1.11 (± 0.77)	43	Large
	Night _{VA}	1.29 \pm 0.35	1.81 \pm 0.68 **	0.96 (± 0.75)	40	Large
CSAI-2 Cognitive Anxiety (on 4)	Day _{SA}	1.20 \pm 0.30	1.12 \pm 0.23 *	0.30 (± 0.72)	- 7	Small
	Night _{SA}	1.24 \pm 0.23	1.39 \pm 0.42	0.41 (± 0.72)	12	Small
	Night _{VA}	1.24 \pm 0.36	1.37 \pm 0.39	0.35 (± 0.72)	10	Small
CSAI-2 Self- confidence (on 4)	Day _{SA}	3.53 \pm 0.44	3.54 \pm 0.43	0.01 (± 0.72)	0	Trivial
	Night _{SA}	3.43 \pm 0.41	2.89 \pm 0.67 ****	0.97 (± 0.75)	- 16	Large
	Night _{VA}	3.41 \pm 0.52	2.88 \pm 0.66 **	0.89 (± 0.75)	- 16	Large

Mean \pm SD are displayed for Days_{SA} (day sound alarm), Nights_{SA} (night sound alarm) and Night_{VA} (night vibrator alarm) conditions at rest and pre-simulated interventions. ES: effect size; CI: confidence interval; CSAI-2: Competitive State Anxiety Inventory - 2; SSS: Stanford Sleepiness Scale. Scores for the SSS were expressed on a 7-point Likert scale and scores for all the CSAI-2 items were expressed on a 4-point Likert scale. *show a significant difference vs. rest with *: $p < 0.05$; **: $p < 0.01$; ****: $p < 0.001$.

4. Discussion

This study aimed to assess the psychophysiological responses of firefighters throughout a simulated rescue intervention performed during the day and at night, in **workplace ecological conditions**. Furthermore, the study aimed to determine if a modified vibrating alarm has an impact on these psychophysiological responses during a simulated intervention performed at night. The main results revealed that during the alarm mobilisation phase, the HR reactivity was higher during the intervention performed at night than the intervention performed during the day, and it can be decreased with the use of a vibrating alarm during the night. During the simulated rescue intervention, no differences in the firefighters' performance and HR responses were found between the day and the night conditions or between the two different alarm signals. However, the cardiac parasympathetic reactivation following the simulated intervention was lower during the night condition than during the day condition. In terms of the psychological responses, the level of sleepiness was higher, and the level of self-confidence was lower before the night-simulated intervention than before the day-simulated intervention. Pre-simulated intervention somatic anxiety increased in comparison to the resting measures for both the day and night conditions, but no differences were found between the two conditions.

Firstly, during the alarm mobilisation phase, HR reactivity was higher in the Nights_{SA} condition than in the Days_{SA} condition (77.2 ± 20.4 vs 65.1 ± 17.9 beats·min⁻¹ respectively). In our study, the HR reactivity measured during the day was slightly higher than those measured in previous studies, i.e. 20 to 61 beats·min⁻¹ (Kuorinka and

Korhonen 1981; Karlsson et al. 2011; Hall et al. 2016). In our study, in the Days_{SA} condition, although the participants were not asleep, they rested in a supine position for about 30 minutes wearing the same attire that was worn in the Nights_{SA} condition. Consequently, the recorded pre-alarm HR was lower in our study than in previous studies, which could explain our higher HR reactivity. Only one study analysed HR reactivity in a night condition, and it found lower HR reactivity values than those measured in our study for the Nights_{SA} condition (Hall et al. 2016). These authors also compared HR reactivity during a day and a night alarm mobilisation phase and showed no significant differences. In our study, the higher HR reactivity in the Nights_{SA} condition in comparison to the Days_{SA} condition was due to a significantly lower pre-alarm HR in the Nights_{SA} condition; the peak HR was not different between the day and night conditions. It is well established that resting HR is influenced by circadian variations, and the lowest values are obtained between 01:00 h and 02:00 h (Harma et al. 1982), as found in our study. Moreover, participants were asleep in the night condition but not in the day condition. This could also influence the resting HR, which is lower when a person is sleeping (Viola et al. 2002). Therefore, the circadian rhythmicity of the resting HR as well as the HR during waking state when waking up, could explain the different HR reactivity found between the Nights_{SA} and the Days_{SA} conditions. ~~Moreover~~ Finally, the alarm mobilisation phase resulted in an increase in pre-intervention systolic BP in comparison to the resting BP values, with no difference between the Nights_{SA} and the Days_{SA} conditions. Both the significant increase in HR and the increase of pre-intervention systolic BP were in accordance with the “fight or flight” reaction of firefighters during the alarm mobilisation phase, as described in previous studies (Hall et al. 2016; Smith et al. 2016).

Secondly, regarding the simulated rescue intervention, our results revealed no difference between the Nights_{SA} and the Days_{SA} conditions for the CT, HR and BP responses. As presented in Table 2, depending on the condition, mean HR ranged between 85% and 86% of HR_{max} and peak HR ranged between 90% and 91% of HR_{max}. These results are similar to those reported by previous studies with simulated firefighting activities (Williams-Bell et al. 2009; Windisch et al. 2017; Marcel-Millet et al. 2018). ~~Moreover~~ The increase in systolic BP during the simulated rescue intervention (Figure 2) was higher in our study than in a previous study (Horn et al. 2011). However, in contrast to our study, in the previous research (Horn et al. 2011), the firefighting activity was longer (i.e. 18 minutes) and it included rest periods, which can decrease the systolic BP. The HR and BP reported in our study showed that the simulated rescue intervention was a strenuous exercise. Otherwise, to the best of our knowledge, our study is the first to compare day- and night-simulated rescue interventions in firefighters. Although the results of studies with healthy subjects have revealed discrepancies, previous findings reported no effect of circadian rhythm on physical performance or physiological responses ($\dot{V}O_2$, HR) during submaximal exercise (Reilly and Brooks 1982; Deschenes et al. 1998) or maximal exercise (Deschenes et al. 1998). Regular training at specific times of the day can influence the diurnal rhythm by limiting the differences between the evening and morning performances (Chtourou and Souissi 2012). Because their shift is 24 hours long, firefighters have to deal with regular interventions at any time of the day or night. Consequently, this regular training may help firefighters perform equally well at night and during the day. Moreover, firefighting activities are a physical stressor and a psychological stressor (Robinson et al. 2013). In response to a stressful situation, the hypothalamic-pituitary-adrenal axis releases cortisol, which allows the body to be on high alert and which may enhance the physical response to an emergency. The cortisol production follows a circadian rhythmicity, but it also includes an adaptive response to the acute stress that firefighters experience before simulated interventions

(Robinson et al. 2013) or during the alarm mobilisation phase (Jay et al. 2019). In our study, for both the Nights_{SA} and the Days_{SA} conditions, peak HR was similar during the alarm mobilisation phase, and there was a similar increase in pre-intervention somatic anxiety (Table 3). These results reveal that the firefighters were in a physically and psychologically stressful situation during the daytime and night-time interventions. Although the adaptive response of the cortisol production was not measured in our study, it may have helped the firefighters perform as well as during the Nights_{SA} condition and the Days_{SA} condition.

Thirdly, the present study aimed to investigate cardiac parasympathetic reactivation after a simulated rescue intervention conducted at night and during the day. In a previous study, we investigated cardiac parasympathetic reactivation after firefighting activities (Marcel-Millet et al. 2018), but to the best of our knowledge, no studies have evaluated it at night. In the present study, the indices of cardiac parasympathetic reactivation were higher than those that were observed previously (e.g. HRR_{60s}, LnRMSSD), which suggests a greater cardiac parasympathetic reactivation in the current study. This difference could be due to the exercise duration, which was longer in the earlier study than in the present experiment (i.e. 13.4 ± 2.1 min vs 4.2 ± 0.6 min) (Marcel-Millet et al. 2018). Indeed, previous research studies have shown that a longer exercise duration may attenuate the post-exercise HRV indices of cardiac parasympathetic reactivation (Michael et al. 2017). Nevertheless, despite the short duration of the simulated rescue intervention in the present study, the recovery indices values are similar to those observed after high-intensity exercises in sports (Buchheit et al. 2007; Nakamura et al. 2009).

Furthermore, while the intensity and the duration were similar between the night- and the day-simulated rescue interventions, the cardiac parasympathetic activity was lower in the Nights_{SA} condition than in the Days_{SA} condition. Few studies have investigated the effect of the time of day on acute post-exercise recovery, with inconsistent results. Some studies reported a lower HR recovery after evening exercise in comparison to morning exercise in healthy subjects (Cohen and Muehl 1977). However, other studies found no differences in acute recovery after morning and night exercise (Harma et al. 1982; Prodel et al. 2017). A higher post-exercise blood lactate concentration would be one possible explanation for the depressed cardiac parasympathetic recovery during the night. Previous studies have reported a circadian variation in blood lactate values after exercises performed at the same intensities (Baxter and Reilly 1983; Deschenes et al. 1998), and it has been shown that the blood lactate concentration was associated with a decrease in cardiac parasympathetic reactivation (Buchheit et al. 2007). It has also been reported that the aerobic contribution during a Wingate test was lower in the morning than in the afternoon (Souissi et al. 2007). The number of cardiovascular events for the United States firefighters is related to the distribution of interventions; in the general population, it follows a circadian rhythm (Kales et al. 2003). The risk of death by coronary heart disease is 10-fold higher during the recovery period after firefighting interventions than during non-emergency duties (Kales et al. 2003). Because weak post-exercise parasympathetic activity is associated with an increased risk of death (Cole et al. 1999; Lahiri et al. 2008), the impaired parasympathetic reactivation after firefighting activities might be one cause of the increased risk of firefighters' death. Finally, all of these results should be considered in the context of the development of stress at work. Indeed, firefighters face many stressful situations, as shown through the HR reactivity during the intervention or through the post-exercise vagal depression. In addition, it has recently been shown that the nocturnal HRV of firefighters is reduced while on-call (Marcel-Millet et al. 2020a). All of these elements can lead to a chronic reduction in HRV in firefighters who experience high job stress, as shown by Shin et al. (2016). Moreover, high

levels of work stress have been shown to affect the development of cardiovascular disease (Belkic et al. 2004; Steptoe and Kivimäki 2012). This is why emergency services should consider implementing strategies to reduce the different sources of stress for firefighters. Among the different strategies that can be adopted, improving the reactivation of the parasympathetic system should be considered. Active cooling strategies, such as hand and forearm immersion, have been proposed to decrease the cardiovascular and thermoregulatory strain of firefighters (Selkirk et al. 2004; Barr et al. 2011). Regarding HRV, both face and body cold water immersion improved cardiac parasympathetic reactivation, in particular thanks to a decrease in the core temperature (Al Haddad et al. 2010; de Oliveira Ottone et al. 2014). In hot conditions, these strategies are necessary to increase exercise tolerance and prevent the firefighters' exhaustion (Selkirk et al. 2004).

In addition, to reduce the stress of firefighters, the second objective of this study was to compare two different types of alarms during the night. The results revealed that the modification of the night alarm signal with a vibrating alarm, which was a softer alarm than the sound alarm, decreased cardiac stress during the alarm mobilisation phase. Indeed, between the Night_{SA} and the Night_{VA} conditions, the pre-alarm HR was similar but HR reactivity in the alarm mobilisation phase was lower in the Night_{VA} condition than in the Night_{SA} condition. Similar results were observed in a previous study, which revealed a lower HR reactivity when participants were gently awakened in comparison to using a sound alarm signal (Hall et al. 2016). However, that study (Hall et al. 2016) modified the alarm signal and the subsequent mobilisation, which implied a lower physical activity in the mobilisation phase. Nevertheless, the significant increase in HR during the alarm mobilisation phase could be due to both the alarm stress and the subsequent movements (Hall et al. 2016). The stress related to the alarm signal seems to contribute significantly to the HR responses, as shown previously in a study with ambulance personnel (Karlsson et al. 2011). A change in a night alarm signal seems sufficient to decrease the cardiac stress related to the emergency alarm. Moreover, no difference was observed between the Night_{SA} and the Night_{VA} conditions for all the other parameters, such as CT and HR, for the simulated rescue intervention and the indices of cardiac parasympathetic reactivation. The triggering of the alarm leads to a "fight or flight" reaction with a prominent sympathetic activation, a massive release of catecholamines and an increased HR (Smith et al. 2016). These elements can be the cause of the significant increase in the risk of death during the alarm response (Kales et al. 2003, 2007). In this context, it would be very interesting for the emergency services to provide firefighters with a modified alarm signal, which could decrease their cardiac stress during the alarm mobilisation phase.

Finally, regarding the psychological measures, the level of pre-intervention sleepiness was higher in the Night_{SA} condition than in the Day_{SA} condition. We also found this difference when we compared the resting measures: the level of pre-intervention sleepiness increased during the night condition, but not during the day condition (Table 3). These results support the findings of previous studies that indicated that sleepiness followed a circadian rhythmicity, with a peak in sleepiness between 03:00 h and 07:00 h (Valdez 2019). This circadian pattern of sleepiness may be related to the melatonin secretion rhythm, which increases during the night (Kazemi et al. 2018). Another possible explanation of the increase in sleepiness may be the sleep restriction generated by the simulated rescue intervention (Philip et al. 2012). Moreover, we found no difference in the level of sleepiness between the Night_{SA} and Night_{VA} conditions. This result is in accordance with the study by Jay et al. (2019), who revealed that a less disruptive awakening did not alter the participants' sleepiness after waking. These are important findings considering that firefighters have to "mobilise", drive and make decisions just after waking up (Jay et al. 2019).

We found a significant difference in the pre-intervention self-confidence between the Night_{SA} and the Day_{SA} conditions. When compared to the resting measures, the participants' level of self-confidence decreased during the night condition but not during the day condition (Table 3). A positive linear relationship between self-confidence and sports performance was found in previous studies (Woodman and Hardy 2003). However, other factors moderated this relationship, such as sex and competitive standards (Woodman and Hardy 2003), which may explain the lack of difference in our study between the firefighters' daytime and night-time performances, although they had lower self-confidence during the night. Nevertheless, it is important for firefighters to consider this decrease in self-confidence because they can be faced with very mentally challenging situations.

In terms of anxiety, the somatic anxiety was higher during the pre-intervention measures than during the resting measures under the day and night conditions, but no differences were found between the conditions (Table 3). Somatic anxiety was defined as “the physiological and affective elements of the anxiety experience that develop directly from autonomic arousal” (p.6) (Martens et al. 1990). Consequently, the increase in somatic anxiety in our study was not surprising, with the activation of the sympathetic nervous system during the alarm mobilisation phase, as measured by the increase of HR (Table 2) and with the likely hypothalamic-pituitary-adrenal axis activation that was measured in previous studies (Robinson et al. 2013; Hall et al. 2016). However, no difference was found for cognitive anxiety, which was defined by Martens et al. (1990) as “the mental component of anxiety and is caused by negative expectations about success or by negative self-evaluation” (p.6). The participants in our study were familiar with the simulated rescue intervention, as it had been part of their occupational skills training. Consequently, they had no doubts about their ability to achieve it successfully. However, it is reasonable to assume that during real interventions, when firefighters are confronted with unpredictable situations with sometimes vital issues, their level of cognitive anxiety may increase. Nevertheless, the increase in the level of somatic anxiety is an important result because it has been shown that there is a curvilinear relationship between somatic anxiety and sports performance (Martens et al. 1990). The increase in anxiety represents an important concern for the health of firefighters, who are significantly affected by coronary heart diseases (Smith et al. 2016). It has been shown that anxiety may increase the risk of coronary heart diseases (Kubzansky et al. 1998). Further studies are required to determine whether the performance and health of firefighters are related to anxiety or/and self-confidence.

There were several limitations to consider in this study. First, due to logistics issues, no **women** participated in this study although they represented 17 % of French firefighters in 2020. This may prevent the generalization of results to female firefighters, as gender may influence performance and physiological responses (Williams-Bell et al. 2009), and as HRV may be influenced by the menstrual cycle (Bai et al. 2009).

Second, the anthropometric data of the participants in this study diverge from the data usually published in firefighters' research, with a lower BMI and a higher estimated $\dot{V}O_{2max}$ in our study (Selkirk et al. 2004; Williams-Bell et al. 2010; Horn et al. 2011, 2019). The study being physically strenuous, it is the most athletic firefighters of the fire station who have volunteered to participate. This difference in fitness may affect the data of our study, a good physical condition allowing to improve the firefighters' performance (Williams-Bell et al. 2009; Marcel-Millet et al. 2020b) without necessarily influencing cardiac parasympathetic reactivation (Marcel-Millet et al. 2020b).

5. Conclusions

In conclusion, the firefighters' cardiac stress in response to the alarm signal was greater during a night-simulated rescue intervention than during the day, and the cardiac parasympathetic reactivation in the post-simulated rescue intervention was more impaired in the night in comparison to the day. Moreover, the firefighters felt sleepier and less self-confident before the night-simulated intervention than before the day-simulated intervention. Nevertheless, the firefighters were equally efficient during the night-simulated intervention and the day-simulated intervention, with similar CT and HR responses between the two conditions. The use of a vibrating signal alarm during the night decreased the firefighters' cardiac stress throughout the alarm signal phase without influencing their subsequent performance, cardiac parasympathetic recovery and psychological arousal.

Regarding the practical applications of the present study, the emergency services should consider implementing strategies to improve parasympathetic reactivation after firefighting activities, especially at night when the disturbance is further increased. Hand and forearm immersion has been proposed as effective cooling strategy to decrease the physiological strain of firefighters (Barr et al. 2011).

Acknowledgments

We would like to acknowledge the firefighters for their participation in this study and their technical support. We also thank the institutional board of the Service Départemental d'Incendie et de Secours du Doubs for its support.

Funding sources

The study was part of the European Cross-border Co-operation Programme (Interreg France-Suisse 2014-2020), and it was supported by a grant from the European Funding for Regional Development (FEDER).

Conflict of interest

No conflicts of interest, financial or otherwise, are declared by the authors. The authors declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

Ethical approval

This study was conducted in accordance with the recommendations of the 1964 Declaration of Helsinki and its later amendments. The research plan was examined and approved by the medical service and the Institutional Review Board of the Regional Fire and Rescue Service of Doubs, and it was approved by the Ethics Committee of the responsible institutional department.

Informed consent

Prior to testing, all participants gave a voluntary written informed consent which indicates the purpose, the benefits and the risks of the investigation and the possibility to stop their participation at any time.

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