International Journal of Occupational Safety and Ergonomics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tose20

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To cite this article: Sylwia Sumińska , Kamila Nowak , Barbara Łukomska & Hanna B. Cygan (2020): Cognitive functions of shift workers: paramedics and firefighters – an electroencephalography study, International Journal of Occupational Safety and Ergonomics, DOI: 10.1080/10803548.2020.1773117

To link to this article: https://doi.org/10.1080/10803548.2020.1773117

International Journal of Occupational Safety and Ergonomics (JOSE), 2020
https://doi.org/10.1080/10803548.2020.1773117

Cognitive functions of shift workers: paramedics and firefighters – an electroencephalography study

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Introduction. Working shifts has a negative impact on employee health and cognitive efficiency. The purpose of this study was to investigate the impact of shift work on cognitive functions – attention and working memory – using both behavioural and electrophysiological measures. *Methods*. The study was carried out on a group of 34 shift employees (18 paramedics, 16 firefighters) and on 17 day workers. Participants performed the attention network test and the N-back task with two conditions (1-back, 2-back) while the electroencephalography signal was recorded. *Results.* Observations included a higher amplitude of the P200 potential in paramedics (compared to the control group), a higher amplitude of the P300 potential after work than on a day off and the lowest increase in power in the θ band after the night shift. In firefighters, lower α desynchronization and lower synchronization in the α/β band were observed after a 24-h shift. Paramedics and firefighters had longer reaction times (N-back task). *Conclusions*. The results suggest that paramedics experience problems with sustained attention. Paramedics process visual stimuli in a different way; after a night shift, performing the tasks required more engagement of cognitive resources. For firefighters, a decrease in visual attention functions and cognitive inhibition was observed.

Keywords: shift work; paramedics; firefighters; cognitive functions; attention; working memory

1. Introduction

According to the definition included in the labour code, shift work stands for doing work according to the established working time, which assumes changing the time of work done by employees after a specific number of hours, days or weeks [1]. Shift work is common in many professions, wherever it is necessary to provide continuous assistance and ensure safety, and in places where continuous working hours result from the nature of the services provided. Shift work is an intrinsic part of rescue service operation.

There are a number of studies that confirm the negative impact of shift work on employee health and its contribution to the onset of chronic diseases. Non-standard working hours and prolonged circadian rhythm desynchronization affect the functions of the digestive system, the nervous system, mental health, sleep conditions and eating habits. They contribute to cardiovascular diseases, diabetes, elevated cholesterol levels and obesity [2–5].

Studies provide evidence that prolonged circadian rhythm desynchronization may lead to impaired sleep, with such symptoms as difficulty falling asleep and reduced sleep quality and duration [6,7]. A meta-analysis revealed that shift work may cause, e.g., chronic sleep deficiency [8]. Consequently, decreased cognitive efficiency is observed, which entails a drop in the quality of work done and in productivity, and an increase in the number of accidents and number of errors made [9–11].

Sleep deprivation has a negative impact on alertness and attention [12–14]. It was proved that people who sleep for shorter periods experience a drop in attention, extended reaction times and deteriorated memory and learning capability [7,10,15–18]. Moreover, persons who currently work shifts achieve poorer results in tests that measure information processing and sustained attention [19], while their verbal memory, short-term memory, attention and learning capability are generally poorer [20]. The results of studies revealed a negative impact of working shifts, desynchronization of the circadian rhythm and sleep deficiency on operational functions, including attention and distractor resistance [21], planning [22] and ability to make decisions [23,24].

The use of an electroencephalography (EEG) test when evaluating cognitive efficiency can provide more information about cognitive engagement. An analysis of evoked potentials, i.e., electric potentials that occur after presentation of a stimulus, can be used for time-accurate data presentation on the stage of information processing and efficiency of cognitive processes. A frequency analysis and an analysis of power changes in time (time–frequency

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*Corresponding author. Email: sysum@ciop.pl, sylsuminska@gmail.com analysis) provide information about the answer components (frequency) [25].

The P300 potential is among the most commonly analysed markers of cognitive activity, whose amplitude decreases as the working memory load goes up [26–28], and is linked to stimulus identification and classification, and information updating in the working memory [29,30]. The N100 potential amplitude, which occurs at an earlier stage, is related to attention allocations and stimuli processing [31]. The contingent negative variation (CNV) is also related to attention stimulation processes, which are observed when a stimulus is preceded by a cue [32]. The P200 potential is, in turn, associated with the early classification of stimuli [33,34].

Brain oscillations have also been indicated as a measure of cognitive processes. Studies prove that a power increase in the θ band (4–6 Hz) can be related to a greater involvement of cognitive control while performing a task [35,36]. The α rhythm (8–13 Hz) is, in turn, linked to engagement of attention processes. An increase in the α band occurs at relaxation or rest, while a power drop (α desynchronization) is proportional to the level of attention stimulation and engagement [37–39], and can be related to the processes of impeding information, which is not relevant for a task [40]. The β rhythm (13–30 Hz) is associated with the involvement of attention processes in doing a task and information selection [41], while an increase in the power spectrum in this band before the task is linked to a better execution level measured by reaction time and answer correctness [42,43].

To our best knowledge, the majority of studies investigating the impact of shift work on cognitive functions applied only behavioural measures – such as accuracy and reaction times in a cognitive task. The few studies that included EEG recording have only been conducted in long-distance drivers [44] and machine operators [45], and did not include repeated measurements. The purpose of our study is to investigate the nature of the shift work impact on attention and working memory using both behavioural and electrophysiological indicators. Moreover, we investigate whether the organization of shift work, i.e., duration of the shifts, has a different impact on cognitive efficiency. The study was adjusted to the nature of work that Polish rescue service workers do and the length of their shifts. Polish paramedics work 12-h shifts and firefighters work 24-h shifts. In comparison to shift workers, we also conducted a study on control group workers (day workers).

The high time-resolution of the EEG allows us to track the stages of information processing, which enables us to reveal which particular processes underlie the poor performance indicated by behavioural measures. We hypothesize that the differences in performance in the two experimental tasks (attention network test [ANT] and N-back task) will be reflected in the different patterns of brain activity indicated by evoked potential amplitudes and/or topography, as well as the power of brain oscillations including θ, α and β frequencies.

We assume that attention and working memory will be at a lower level in shift workers – paramedics and firefighters – compared to the control group, which will be observed as a lower level of task performance, prolongation of the response time, a decrease in accuracy and an increase in errors in the N-back task and the ANT. They will display trouble in various aspects of attention, in sustained attention and working memory – task switching, inhibiting reactions, selecting responses. Their results will also be reduced in the measurement after the night/day shift compared to the measurement on a non-working day.

2. Materials and methods

2.1. *Study population*

The study was carried out in two groups of shift workers – 18 paramedics working on 12-h shifts (day and night shifts) and 16 firefighters working on 24-h shifts with a 48-h break from work – and 17 persons working during the day, who were the control group. The subjects were young persons (up to 45 years of age), with at least 5 years of job seniority and no history of severe head injuries, chronic diseases or taking medications affecting nervous system function. The study was carried out in the Central Institute for Labour Protection – National Research Institute in Warsaw from May to November 2018.

2.2. *Procedure*

The measurement was performed three times for each group. Depending on the group, functioning after a night shift (paramedics)/24-h shift (firefighters), a day shift (paramedics, control group), a day off in the morning (firefighters, control group) and a day off in the evening (all groups) was checked. The procedure included two tasks, during which the electrical activity of the brain was recorded. The ANT [46,47] measures attention function aspects, which included alerting, orienting, information selection and executive control. The task involved showing the direction of an arrow surrounded by arrows with the same orientation (congruent condition) or opposite orientation (incongruent condition). The tasks were performed in three conditions: the central cue condition (W1), which preceded the arrows; the spatial cue condition (W2), which suggested the place where arrows appeared; and the no cue condition (W3). The subject responded by pressing a relevant key on a computer keyboard. In each condition (W1, W2 and W3), 48 stimuli congruent with and 48 stimuli incongruent with the reference stimulus were presented (Figure 1).

The second task, the N-back task [48], was used to measure working memory under increasing cognitive load. White letters of the alphabet presented against a black

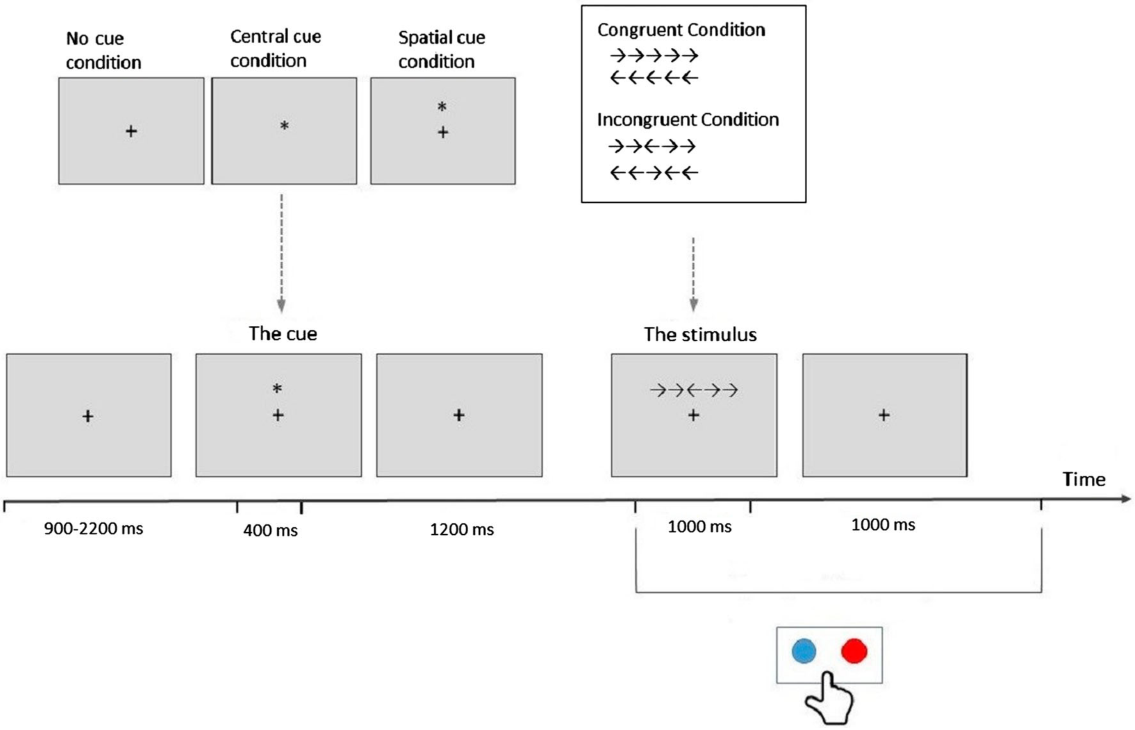

Figure 1. Attention network test pattern. Note: * cue; + fixation point.

background (angle of vision <5°) were the stimuli used in the task. The subjects had to indicate whether the presented letter was the same as (matched stimuli) or different from (non-matched stimuli) the letter presented one position (1-back) or two positions (2-back) back, respectively, depending on the condition. The task included 180 repeated stimuli and 60 non-repeated stimuli (Figure 2).

The tasks were presented with Presentation version 20.0. In both tasks, the cognitive efficiency was evaluated based on the answer correctness and reaction time, while in the N-back task the mistakes were also analysed (omissions and false alarms). The evoked potentials (CNV, N170, P200 and P300) and the relative power increase/decrease in the α, θ and β bands were the neurophysiological indicators.

The EEG signal was recorded using EEG equipment (G.Tec Medical Engineering GMBH, Austria) with a 256-channel amplifier (g.Hlamp; G.Tec Medical Engineering GMBH, Austria). Thirty-two recording electrodes were used, arranged according to the international 10–20 system. The central electrode (Cz) was the reference electrode. The resistance on each electrode was kept below 20 kΩ during recording. The signal was recorded at a sampling frequency of 256 Hz.

2.3. *Preparation and analysis of EEG signal*

The obtained EEG raw data were pre-processed in EEGLAB version 14.1.2b [49] operating in the Matlab environment version R2018a. Prior to signal analysis, the markers of the stimuli to which the subjects responded incorrectly were removed. The data were then filtered with a 0.1-Hz high-pass filter (finite impulse response [FIR] filter). The next stage included visual inspection of the signal for each subject to remove the electrodes that recorded noisy (polluted) signals and to reconstruct the signal on the missing electrodes, as well as to remove major artefacts (e.g., due to motion). The reference was changed to the mean from the electrodes and the signal was refiltered in the band 1–32 Hz. Then, an independent component analysis (ICA; Infomax algorithm) [50] was conducted. The purpose of the analysis was to separate and remove the components related to eye movement and blinking.

2.4. *Evoked potentials*

In the N-back task, the signal was divided into segments against the markers of matched and non-matched stimuli in the 1-back and 2-back conditions. The segments lasted 1700 ms and covered 200 ms before the stimulus presentation and 1500 ms after. The time before the stimulus (–200 to 0 ms) was used as the reference period (i.e., baseline) for further signals. The mean of the signals was then derived to obtain the evoked potentials in response to subsequent stimuli. In the ANT, the signal was divided for proper stimuli into 3300-ms sections covering 1800 ms before the proper stimulus (i.e., 200 ms before a tip, if it preceded a stimulus) and 1600 ms after a stimulus. The time before the stimulus (–200 to 0 ms) was used as a reference period for the signal after the beginning of stimulus presentations.

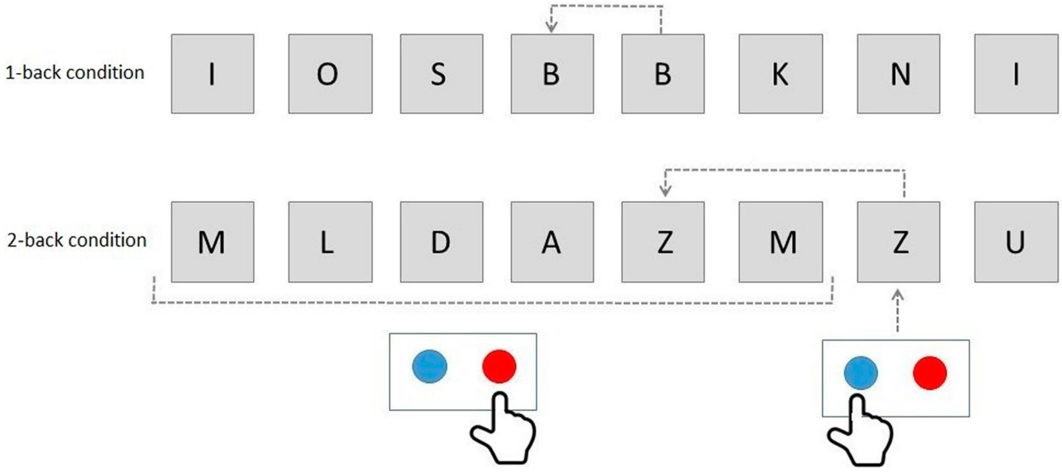

Figure 2. *N*-back task pattern. Note: Left button, matched stimuli; right button, non-matched stimuli.

The mean of the segments was then developed to obtain the evoked potentials in response to the stimuli presented under each condition.

2.5. *Relative power increase/decrease*

Frequency analysis was conducted using the event-related spectral perturbation (ERSP) method [49]. In the *N*-back task, the signal was divided into segments lasting 2600 ms around each type of the presented stimuli, i.e., matched and non-matched in each condition. The segments covered the time of 600 ms before a stimulus and 200 ms after a stimulus. Changes in the signal power (in decibels) were observed for the reference period of −600 to 100 ms before the stimulus presentation. In the ANT, 5600-ms segments were separated (2600 ms before the stimulus, 3000 ms after the stimulus). Changes in the signal power were observed for the reference period of −2100 to –1700 ms before the stimulus presentation. Then, an analysis of frequency changes in time was performed for the band 4–30 Hz, which included θ (4–7 Hz), α (8–13 Hz) and β (14–25 Hz) frequencies. Calculating the power spectrum in the time and frequency domain for each subject and experimental condition was made using the discrete wavelet transform method.

2.6. *Statistical analysis*

A comparison of measurements obtained on the day off in the evening, for three groups, was carried out using the Kruskal–Wallis test. Analysis with the Mann–Whitney *U* test served to compare the groups of paramedics and firefighters after a night shift (12-h) or 24-h shift, the paramedics and day shift workers after a day shift, and the firefighters and day workers on their day off in the morning. Comparisons were also made inside the groups, including differences in cognitive efficiency after a day shift, a night shift and a day off for the paramedics (Friedman's analysis of variance [ANOVA]) and after a 24-h shift and a day off in the morning for the firefighters (Wilcoxon test).

3. Results

3.1. *Demographic variables*

The group of paramedics included 12 men and 6 women. The group of firefighters consisted of 16 men, and the control group was composed of 15 men and 2 women. The groups varied for their gender composition ($\chi^2 = 7.413$; $p = 0.025$). The studied groups did not differ for their age (Kruskal-Wallis test, $p = 0.697$), years of education ($p = 0.959$), years of professional experience ($p = 0.372$) or chronotype (χ^2 test, $p = 0.101$). The mean age in the group of paramedics was 31.83 years (*SD* 4.73), for firefighters was 33.19 years (*SD* 5.47) and for the control group amounted to 33.0 years (*SD* 4.32). The mean job seniority of the paramedics was 17.17 years (*SD* 2.64), for the firefighters was 17.47 years (*SD* 3.25) and for day shift workers was 17.71 years (*SD* 2.93). The groups varied for their mean sleep duration ($\chi^2 = 19.141$; $p < 0.001$). Pair comparisons (Mann–Whitney *U* test) demonstrated that sleep duration was shortest in the group of paramedics (*M* 5.61, *SD* 1.02), and was statistically shorter than among firefighters (*M* 6.75, *SD* 0.69; $Z = -3.101$; $p = 0.002$) and in the control group (*M* 7.18, *SD* 0.73; $Z = -3.944$; $p < 0.001$). The paramedics had less time to sleep during their night shift (*M* 2.83 hour) than firefighters during their 24-h shift (*M* 5.37 hour, *SD* 1.52; $Z = -2.143$; $p = 0.032$).

3.2. *Shift workers and day workers*

There were no statistically significant differences between the groups on a day off in the evening in reaction time for the *N*-back task (1-back, $p = 0.460$; 2-back, $p = 0.650$) or in answer correctness (1-back, $p = 0.290$; 2-back,

Table 1. Reaction time to a matched and non-matched stimulus in the N-back task.

	1-Back condition		2-Back condition	
Measurement	Matched stimulus	Non-matched stimulus	Matched stimulus	Non-matched stimulus
After a day shift, P vs C	P: M 449.13, SD 91.29	P: M 393.70, SD 46.44	P: M 450.56, SD 102.8	P: M 357.07, SD 86.31
	C: M 410.41, SD 56.10	C: M 433.16, SD 74.88	C: M 394.20, SD 54.68	C: M 410.75, SD 54.68
	$U = 118.0; p = 0.248$	$U = 89.0; p = 0.035$	$U = 87.0; p = 0.029$	$U = 79.0; p = 0.015$
Day off in the morning, F vs C	F: M 411.93, SD 56.28	F: M 385.53, SD 49.31	F: M 410.0, SD 49.85	F: M 383.67, SD 52.64
	C: M 428.59, SD 71.73	C: M 376.09, SD 46.71	C: M 374.90, SD 68.04	C: M 395.19, SD 63.91
	$U = 112.0; p = 0.558$	$U = 117.0; p = 0.692$	$U = 73.0; p = 0.04$	$U = 122.0; p = 0.835$
Day off in the evening	P: M 417.72, SD 66.52	P: M 396.07, SD 61.38	P: M 421.62, SD 75.37	P: M 391.02, SD 103.4
	F: M 368.40, SD 34.01	F: M 401.07, SD 47.09	F: M 405.33, SD 110.9	F: M 421.13, SD 57.85
	C: M 381.88, SD 47.14	C: M 428.06, SD 61.68	C: M 373.12, SD 53.06	C: M 428.59, SD 78.45
Day off in the evening, P vs C	$U = 105.0; p = 0.113$	$U = 116.0; p = 0.222$	$U = 90.0; p = 0.038$	$U = 106.0; p = 0.121$
Day off in the evening, F vs C	$U = 103.5; p = 0.365$	$U = 102.0; p = 0.335$	$U = 109.5; p = 0.496$	$U = 120.0; p = 0.777$
Day off in the evening, P vs F	$U = 70.0; p = 0.019$	$U = 126.5,0; p = 0.759$	$U = 101.0; p = 0.219$	$U = 90.5; p = 0.108$

Note: Comparison of measurements between two groups with the Mann–Whitney U test. C = control group; F = firefighters; P = paramedics.

Table 2. Reaction time and answer correctness for all conditions of the ANT.

Behavioural measure	No cue condition	Central cue condition	Spatial cue condition	Congruent condition	Incongruent condition
			Day off in the evening		
Reaction time	P: M 561.17, SD 74.09	P: M 550.05, SD 68.58 F:	P: M 520.60, SD 82.65	P: M 496.16, SD 69.28	P: M 591.72, SD 82.04
	F: M 566.29, SD 74.71	M 550.10, SD 76.49 C:	F: M 523.12, SD 80.08	F: M 504.74, SD 78.05	F: M 588.27, SD 78.28
	C: M 524.50, SD 85.31	M 515.13, SD 86.83	C: M 483.96, SD 78.32	C: M 467.35, SD 80.55	C: M 548.37, SD 86.73
Answer correctness	P: M 0.95, SD 0.08	P: M 0.95, SD 0.06	P: M 0.95, SD 0.07	P: M 0.97, SD 0.07	P: M 0.93, SD 0.07
	F: M 0.93, SD 0.13	F: M 0.94, SD 0.10	F: M 0.94, SD 0.12	F: M 0.95, SD 0.09	F: M 0.92, SD 0.14
	C: M 0.97, SD 0.06	C: M 0.97, SD 0.04	C: M 0.97, SD 0.05	C: M 0.99, SD 0.03	C: M 0.95, SD 0.07
			Day off in the morning		
Reaction time	F: M 561.16, SD 64.05	F: M 558.82, SD 74.61	F: M 522.28, SD 75.13	F: M 508.72, SD 73.58	F: M 586.12, SD 70.35
	C: M 515.66, SD 50.47	C: M 507.00, SD 58.45	C: M 473.14, SD 60.74	C: M 458.83, SD 51.39	C: M 538.37, SD 61.64
Answer correctness	F: M 0.94, SD 0.14	F: M 0.94, SD 0.12	F: M 0.94, SD 0.12	F: M 0.96, SD 0.11	F: M 0.93, SD 0.15
	C: M 0.99, SD 0.02	C: M 0.98, SD 0.02	C: M 0.99, SD 0.01	C: M 1.00, SD 0.01	C: M 0.97, SD 0.003

Note: Measurements on the day off in the morning and evening. ANT = attention network test; C = control group; F = firefighters; P = paramedics.

$p = 0.670$). Paramedics (M 10.72, SD 6.45) omitted more items than members of the control group (M 7.06, SD 6.48) in the 1-back condition on the day off in the evening ($U = 93.0; p = 0.047$).

Analyses revealed statistically significant differences in the reaction time to a matched and non-matched stimulus. After a day shift, the control group had much longer reaction times than the group of paramedics when responding to a non-matched stimulus in the 1-back and 2-back conditions, but shorter reaction times than the paramedics when responding to matched stimuli in the 2-back condition. On their day off in the evening, the paramedics had significantly longer reaction time than the control group when responding to matched stimuli in the 2-back condition and longer than firefighters in the 1-back condition (Table 1).

In the ANT, analysis of the reaction time (W1, $p = 0.098$; W2, $p = 0.15$) and answer correctness (W1, $p = 0.45$; W2, $p = 0.4$; W3, $p = 0.66$) for the three studied groups did not reveal statistically significant differences for the majority of the conditions. The differences occurred only in the no cue condition ($\chi^2 = 6.092$; $p = 0.048$). Paramedics ($U = 86.0$; $p = 0.027$) and firefighters ($U = 74.0$; $p = 0.043$) had longer reaction times than the control group on their day off in the evening. Paramedics had a lower answer correctness level than the control group after a day shift in the congruent condition ($U = 74.0$; $p = 0.046$). Statistical details are presented in Table 2.

Statistically significant differences were also observed suggesting poorer functioning of firefighters than the control group on their day off in the morning. The firefighters had lower answer correctness when responding in the congruent condition in the ANT ($U = 75.0$; $p = 0.045$), and longer reaction times when answering after a central cue ($U = 67.0$; $p = 0.036$) and no cue ($U = 66.0$; $p = 0.033$). Moreover, on the day off in the morning, the group of firefighters had longer reaction times than the control group when responding to matched stimuli in the 2-back condition.

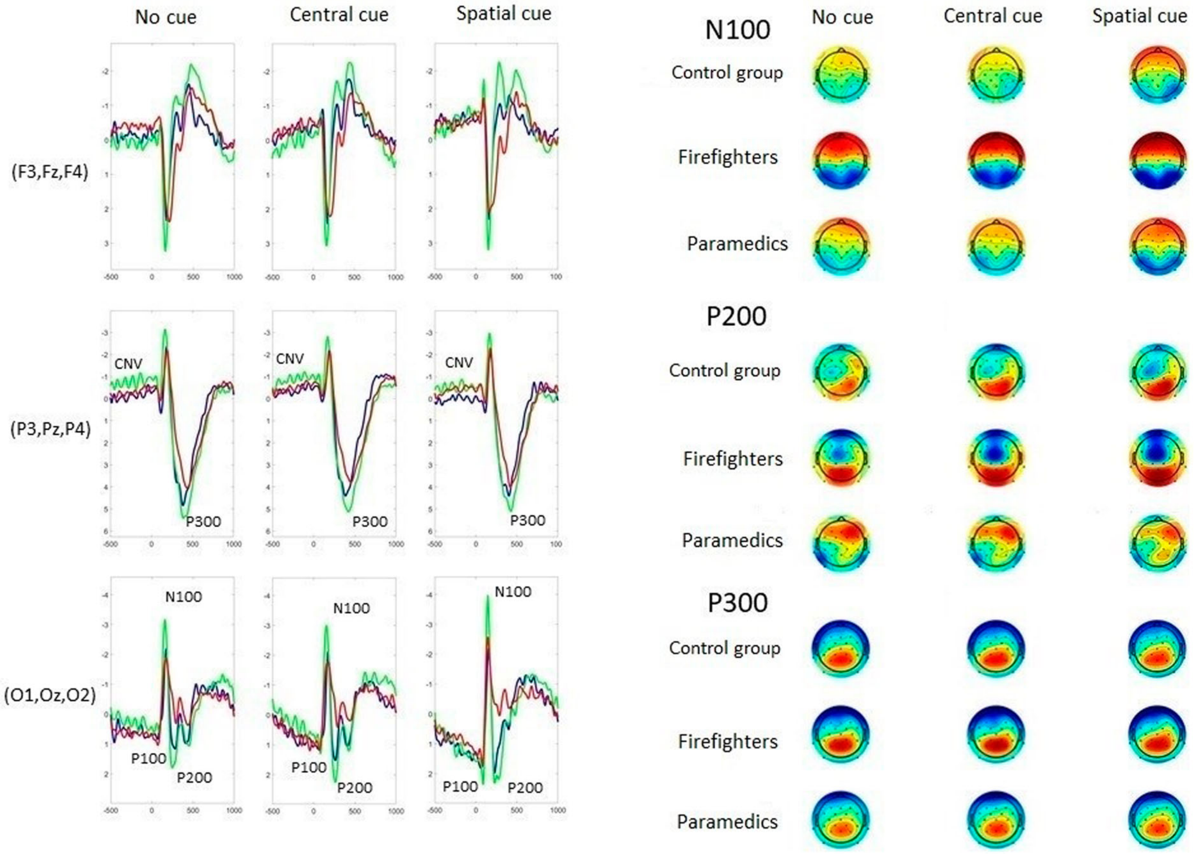

Figure 3. Evoked potentials in the attention network test to proper stimuli presented in all conditions during recording on the day off in the evening. Note: The full colour version of this figure is available online. CNV = contingent negative variation. Red, paramedics; green, firefighters; blue, control group.

3.2.1. *Electrophysiological response*

Statistically significant differences in the amplitude of the evoked potentials occurred only in the ANT for one of the analysed evoked potential components: the P200 potential. The comparisons of measurements between the groups for the day off in the evening revealed that the potential amplitude was significantly higher on the frontal electrodes (mean of F3, Fz, F4) and significantly lower on the occipital electrodes (mean of O1, Oz, O2) in the group of paramedics as compared to the group of firefighters for all experimental conditions, and higher on the frontal electrodes as compared to the control group in the central cue condition (Figure 3). Table 3 presents the results of the statistical analyses.

The differences between the groups in the relative change of the EEG signal power for the θ, α and β bands in the ANT and the N-back task were not statistically significant.

3.3. *Employees working 12-h shifts versus employees working 24-h shifts*

There were no statistically significant differences in the N-back task between paramedics (after a night shift) and firefighters (after a night shift) with regard to reaction time (1-back, $p = 0.97$; 2-back, $p = 0.09$) or answer correctness (1-back, $p = 0.83$; 2-back, $p = 0.31$). In the ANT, no significant differences were revealed for reaction time (W1, $p = 0.69$; W2, $p = 0.84$; W3, $p = 0.84$) or answer correctness (W1, $p = 0.41$; W2, $p = 0.99$; W3, $p = 0.47$).

No differences were revealed in the EEG signal record in the amplitude of the evoked potentials or for the selected α, β and θ bands.

3.4. *Paramedics (working 12-h shifts)*

The analysis did not reveal a lower level of performance among paramedics in any N-back task condition – 1-back ($p = 0.8$) or 2-back ($p = 0.85$) after any shift (day, night, day off in the evening) – or that paramedics had longer reaction time in the 1-back ($p = 0.510$) or 2-back ($p = 0.350$) condition. The analyses show minor differences in the number of mistakes made. Statistically significant differences were observed in the 1-back condition with regard to omissions ($\chi^2 = 6.222$; $p = 0.045$) and false alarms ($\chi^2 = 6.5$; $p = 0.039$). More omissions were observed among the paramedics after a night shift compared to the day shift and more false alarms in reference

Table 3. P200 potential in the ANT on the frontal and occipital electrodes.

Condition	Electrode	χ^2, Kruskal–Wallis test	p	p (P vs C)	p (P vs F)
No cue	Frontal Occipital	9.58 11.81	0.008 0.003	0.082 0.070	0.009 0.002
Central cue	Frontal Occipital	13.78 10.01	0.001 0.007	0.030 0.084	0.001 0.007
Spatial cue	Frontal Occipital	6.86 6.08	0.032 0.048	0.188 0.420	0.036 0.044
Congruent	Frontal Occipital	12.00 12.34	0.002 0.002	0.107 0.101	0.002 0.002
Incongruent	Frontal Occipital	11.21 9.96	0.004 0.007	0.064 0.092	0.004 0.007

Note: Kruskal–Wallis test with Dunn's post-hoc test. ANT = attention network test; C = control group; F = firefighters; P = paramedics.

to the day off. The applied paired comparisons (Dunn's post-hoc test) revealed that the differences did not exceed the statistical threshold level (the result was corrected for the omission index, $p = 0.091$, and false alarms, $p = 0.166$).

The analysis did not show a significantly lower ANT performance (W1, $p = 0.43$; W2, $p = 0.42$; W3, $p = 0.85$) after any shift or significantly different reaction times (W1, $p = 0.16$; W2, $p = 0.13$; W3, $p = 0.16$).

3.4.1. *Electrophysiological response*

The analyses revealed statistically significant differences with regard to the evoked potentials in the N-back task. In the 1-back task, statistically significant differences were observed for the P300 potential in response to a non-matched stimulus (Friedman's ANOVA, $\chi^2 = 7.412$; $p = 0.025$) and a matched stimulus ($\chi^2 = 7.882$; $p = 0.019$). Paired comparisons showed that the amplitude of the P300 potential in response to a non-matched stimulus was higher after a day shift than on the day off ($p = 0.030$), while for the matched stimulus it was significantly lower on the day off than after a day shift ($p = 0.006$) and a night shift ($p = 0.001$). Statistically significant differences for the evoked potential were also observed in the 2-back condition in response to non-matched stimuli ($\chi^2 = 10.706$; $p = 0.005$) and matched stimuli ($\chi^2 = 15.176$; $p = 0.001$). For both the non-matched and matched stimuli, the P300 potential amplitude was lower in the session carried out on the day off than after a day shift (non-matched stimuli, $p = 0.018$; matched stimuli, $p = 0.006$) and after a night shift (non-matched stimuli, $p = 0.011$; matched stimuli, $p = 0.001$).

A power increase for the analysed bands was observed in the θ band following a stimulus presentation in both tasks. In the N-back task (1-back condition, time window 100–500 ms), after a stimulus on the Oz electrode for the non-matched stimulus ($\chi 2 = 6.706$; $p = 0.035$) a significantly higher power increase was observed after a day shift than after a night shift ($p = 0.030$), while for the matched stimulus ($\chi^2 = 7.882$; $p = 0.019$) the power increase was significantly higher on the day off in the evening than after a night shift ($p = 0.018$). In the 2-back condition, the power increase in the band on the Cz electrode was significantly lower after the night shift than after a day shift ($p = 0.049$) and on the day off ($p = 0.018$). Moreover, for the same condition, in the α band (9–13 Hz) in the time window 200–800 ms after a non-matched stimulus, statistically significant differences were observed on the Oz electrode ($\chi^2 = 6.706$; $p = 0.035$). Desynchronization in the band was greater after a night shift than after a day shift ($p = 0.030$).

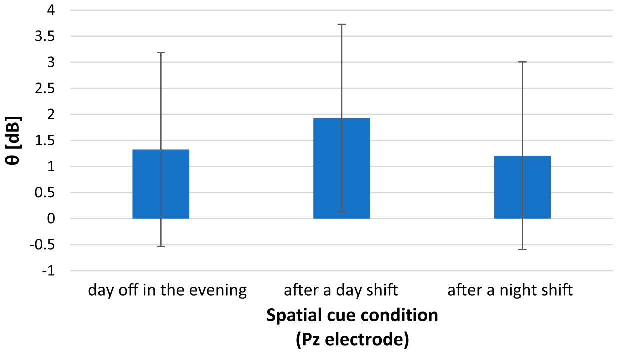

Figure 4. Relative value of power (mean and standard deviation) on the occipital electrode in the θ band in the time window of ca. 100–500 ms after presentation of the proper stimulus in the spatial cue condition in the attention network test in the group of paramedics.

In the ANT, in the spatial cue condition, statistically significant differences were observed in the θ band ca. 100–500 ms after a stimulus on the Pz electrode ($\chi^2 = 9.882$; $p = 0.007$). The observed power increase in the θ band was significantly higher after the day shift than after the night shift ($p = 0.006$; Figure 4). In the incongruent condition, statistical differences were observed for the α band ca. 200–1400 ms after stimulus presentation ($\chi^2 = 6.118$; $p = 0.047$). Desynchronization was greater after a night shift than after a day shift ($p = 0.049$).

3.5. *Firefighters (24-h shift workers)*

The analyses did not reveal significantly different answer correctness in the 1-back ($p = 0.170$) or 2-back ($p = 0.07$) conditions after a 24-h shift than on the day off in the morning. Firefighters did not have significantly longer reaction times in the 1-back ($p = 0.230$) or 2-back ($p = 0.190$) conditions either.

The analysis did not show statistically lower levels of the ANT performance (W1, $p = 0.680$; W2, $p = 0.840$; W3, $p = 0.530$) after a 24-h shift compared to a day off, and the firefighters achieved significantly different reaction times (W1, $p = 0.960$; W2, $p = 0.690$; W3, $p = 0.780$).

3.5.1. *Electrophysiological response*

The comparisons of the amplitudes of the evoked potentials did not reveal statistically significant differences for any component of the EEG signal in any of the conditions of the N-back task and the ANT.

Statistically significant differences were demonstrated for the 2-back condition for the α/β (1000–1500 ms) and α (200–800 ms) bands. Synchronization in the α/β band was significantly higher for the non-matched stimuli on the Cz electrode during recording on the day off than after a 24-h shift ($Z = -1.988$; $p = 0.047$). Desynchronization in the α band on the Pz electrode was lower after a 24-h shift than on the day off in the morning ($Z = -2.442$; $p < 0.015$).

No statistically significant differences were revealed in the ANT for the analysed bands.

4. Discussion

The study results show some differences in cognitive efficiency between shift workers and day workers. In the majority of cases, the differences apply to 12-h shift workers, namely paramedics. Minor differences were revealed in the number of mistakes made, reaction times and electrophysiological responses.

Paramedics reveal difficulty in the tasks that require sustained attention. This is confirmed by the results of other studies on shift workers [10,16,20]. Shift workers find it difficult to stay focused and have longer reaction times to sudden and unexpected events. They react faster compared to day workers in schematic situations, when there is no need to change the reaction, and to non-matched stimuli in the N-back task, which were more abundant and there was no need to recognize and respond quickly upon recognizing the proper stimulus. In the group of paramedics, the risk of making a mistake is higher after a night shift.

The results obtained in our study comply with the source data findings concerning shift work. Previous studies revealed that nurses working on 12-h shifts suffer a higher risk of making a mistake, their reaction time is longer and the quality of their work decreases [51,52]. The literature data show that extended working time, over 8 h a day, causes greater fatigue, leads to mistakes and decreases productivity [53]. One study demonstrated that nurses working on 12-h shifts achieve worse results on the second day of work compared to the first, in alertness tests. The authors concluded that a shorter amount of sleep between shifts affected performance and caused more frequent episodes of inattention [54].

Furthermore, there is a lot of evidence to confirm that circadian rhythm desynchronization and sleep deficiency affect operating functions. The results of the presented studies revealed that shift workers needed more time to identify the stimulus matched to the right stimulus in the N-back task. Since stimuli different from the one presented were in the majority and responding to them could not become schematic, when the matched stimulus appeared unexpectedly, the subjects had to inhibit their schematic reaction. Reaction inhibition, as a component of operational functions of a system within working memory [55], is reduced in shift workers, suggesting that they also have problems with operational functions.

A dual-task or task-switching paradigm is often used for the evaluation of operational functions, more precisely for cognitive flexibility [56–60]. Deterioration of cognitive functions, which is evidenced by a drop in cognitive flexibility and deficits with regard to schematic reaction inhibition, is observed in shift workers who find it more difficult to adapt to shift work [61]. Cognitive flexibility of night shift workers was analysed through evaluation of their ability to follow the instructions of a previous task and to switch tasks (task-switching paradigm). The subjects had to choose (between two answers) the sex, race and emotional expression of presented faces. The questions included three different task instructions, i.e., following the presented instructions entailed task switching. The studies revealed that, besides sleeping problems, shift workers experience reduced cognitive flexibility. The difficulty in returning to a previous task (set inhibition) resulted in additional working memory load, accuracy reduction, a lower task completion rate and an increase in the number of mistakes. The set switching difficulty suggested lower effectiveness and efficiency, was related to a longer task completion time and highlighted lower cognitive flexibility, which required putting in more effort when switching between instructions. Cognitive flexibility is important from the point of view of the quality of the work done, as well as shift work. A more intensive cognitive load, which is related to switching between tasks, contributes to a decrease in effectiveness and an increase in the time necessary to complete a task. A cognitive flexibility drop causes deficits in sustained attention and switching observed in night workers, and, hence, leads to the reduced quality of their work compared to day workers.

Job characteristics often require the monitoring of changes in the environment and obtaining new information in order to adapt one's behaviour and reaction. It was observed that nurses have to be flexible in their approach to patients, taking into account the latter's changing condition and needs in order to provide the right level of medical care [62]. Cognitive flexibility enables effective functioning in a dynamic environment. It is a key ability of rescue workers, as it is necessary when switching instantly to another task, which is more urgent, and doing it effectively. Delayed reactions or mistakes made during work can have dramatic effects, increase the number of casualties or cause severe injuries [61].

Poorer results on the day off (longer reaction times and lower correctness level of answers in some tasks) in the group of shift workers can suggest insufficient body recovery after shift work. The majority of such results occurred in the group of firefighters, whose measurements were performed on the day off in the morning, and most probably this was their first day off after a night's sleep. The available literature data suggest that at least 2 days off are necessary for the body to recover, because recovery occurs only on the second day off. The process of body recovery in night shift workers can be extended and, thus, a suggestion was made to introduce 3 days off after seven subsequent night shifts [63]. Other studies also revealed that an instant comeback to work after the end of a shift has a negative impact on the employee's cognitive skills. A 10-h break between shifts causes restless sleep in nurses [64]. It was also observed that coming back to work within 8 h (following an 8-h shift) results in reduced alertness during the shift [65]. One study examined whether the introduction of 24-h breaks after a day or night shift could have a positive impact on fatigue and alertness. The results revealed higher alertness and lower fatigue compared to persons who did not have such breaks [66].

The analysis of the reference electrophysiological data revealed minor, although significant, differences between shift workers, who worked 12-h shifts, and day workers. The differences occurred in the ANT, which required sustained attention and applied to the P200 potential. The literature links the potential to early evaluation and classification of stimuli [33,34]. Previous studies, whose procedures included the ANT, identified some differences in the CNV, P100, N100 and P300 potentials [32,67,68]. There are no reports concerning the P200 potential in the task. The differences in the potential observed in the study suggest that employees of 12-h shifts, i.e., paramedics, process visual stimuli in a different way in attention-engaging tasks.

The differences between the sessions in the group of paramedics concerning power changes in the θ and α bands, and a higher power increase in the θ band following a spatial cue after a day shift than after a night shift, suggest that a response to a cue in the ANT can be related to the fatigue level in this group of employees. A spatial cue triggered a stronger electrophysiological response after a day shift than after a night shift. The differences observed in the α band in the incongruent condition in the ANT, namely, band desynchronization after a night shift is greater than that after a day shift, also suggest that after a night shift the incongruent (conflicting) stimuli caused a stronger electrophysiological response. Synchronization in the α band is related to stronger cognitive engagement or inhibition of stimuli processing [69], which means that greater desynchronization can mean deeper stimulus processing. The obtained results suggest reduction in cognitive inhibition after a night shift, which conforms to previous findings on the impact of shift work [70].

Differences in the P300 potential in the N-back task were observed in the group of paramedics. The amplitude of the potential was higher in both sessions, which took place after work, i.e., after a day and night shift, than on the day off. Many factors were proven to affect the P300 potential, e.g., degree of attention engagement and stimulus significance. The amplitude of the potential is higher when more cognitive resources are involved in stimulus processing [29]. The higher amplitude of the potential after work observed in the study suggests that doing the tasks after work required more focus of attention and greater engagement of cognitive resources than on the day off. The results comply with the ones obtained for the α band, which suggests greatest desynchronization after a night shift, related to deeper stimulus processing.

The synchronization observed in the group of firefighters in the band 10–20 Hz, occurring 1000–1500 ms after stimulus presentation, was significantly higher on the day off (in the morning) than after a 24-h shift. This can be understood in two different ways. Studies pertaining to working memory associate the power increase in the α band with inhibition of external stimuli, which could disturb the process of stimuli retention in the memory buffer [35], while the β band is related to visual attention [43]. The amplitude increase in the band 10–20 Hz in the period between stimuli presentation in the N-back task can be testimony to the inhibition of stimuli, which could disturb the process of information retention in the memory. In addition, it suggests a higher level of visual attention in preparation for another stimulus. The mechanism could be slightly impaired as a result of fatigue, which occurs after a 24-h shift, with regard to the lower synchronization observed in the band.

Minor differences in behaviour results between groups in the N-back task (longer reaction times to a matched stimulus in the group of shift workers, higher number of omissions in the group of paramedics) were not confirmed by the EEG results, for which no statistically significant differences were revealed between the groups on the day off, or the evoked potentials and the analysed frequencies.

For the differences in the sessions between the studied groups, it was demonstrated that paramedics were more prone to making mistakes after a night shift. Statistically significant differences were also revealed in the electrophysiological response of the brain, where the lowest power increase in the θ band following the stimulus was observed after the night shift, and a higher power increase in the α band also after a night shift compared to the first day. The night and day shifts differed from the day off with regard to the P300 potential. An increase in the amplitude was observed after a day shift and a night shift.

The evoked potentials in the ANT in the group of paramedics differed from the other two groups in the amplitude of the P200 potential. Positive activity at the frontal electrodes was observed only in the group of paramedics. In the case of differences in the behaviour results between the groups on the day off in the evening, longer reaction times were observed in firefighters and in the control group when answering without a cue. In the N-back task, desynchronization in the α band was greater on the day off in the morning than following a 24-h shift, and the task was performed more effectively.

Both the behavioural and the electrophysiological results suggest problems with cognitive inhibition, which is part of the executive functions. The group of paramedics revealed difficulty in schematic reaction inhibition, and conflicting stimuli triggered a stronger electrophysiological response. Cognitive inhibition was weaker after the night shift, when a higher risk of errors occurred. The number of omissions, i.e., lack of right answers, was also higher in this group of subjects.

5. Study limitations

The study results must be approached cautiously due to the limited number of group members, which is common in longitudinal studies. Some differences in the EEG signal did not reveal any statistical significance due to the high individual differences in the recorded signal. The results suggest that shift work affects brain functions. The results and experiments carried out in the project can be treated as a starting point for further studies. Research should be carried out in different age groups and in comparison to slow turnover of shifts and shorter shifts. Factors which may alleviate the negative impact of shift work include slow turnover of shifts [16,17], breaks to rest during work [71–73] and shorter shifts [74].

6. Conclusion

The results of the presented study prove that shift workers, especially those who work 12-h shifts, sleep less and have less opportunity to sleep during work, experience a decrease in alertness and an increased risk of making mistakes. The recording of the brain responses revealed that there were differences in information processing between shift workers and day workers. A decrease in cognitive efficiency was observed both after a night shift and on the day off. The results of the presented study suggest that changes should be introduced to the shift work system to enable body recovery processes.

Disclosure statement

No potential conflict of interest was reported by the authors.

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