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ORIGINAL PAPER

Climate conditions and work-related fatigue among professional drivers

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Abstract

The possible associations between climate parameters and drivers' fatigue have not been subject to specific studies thus far. We have undertaken a study to investigate whether the particular climate parameters are related to fatigue perception by motor vehicle drivers. The study was performed from July to October. Each driver was surveyed four times: before and after workshift on a monotonous route outside the city center (MR), and on a heavy traffic route in the city center (HTR). The study was conducted among 45 city bus drivers aged 31–58 years (43.7 ± 7.9), seniority as driver 3–34 years (14.7 ± 8.6). Data on climate conditions (ambient temperature, air pressure, humidity, wind speed, precipitations) on particular study days was obtained from the Institute of Meteorology and Water Management, National Research Institute Warsaw, Poland. Fatigue was assessed using the Fatigue Assessment Questionnaire, developed at Nofer Institute of Occupational Medicine (Lodz, Poland). The total level of fatigue was significantly ($p = 0.045$) higher after driving on HTR than on MR. The number of symptoms was also significantly higher ($p < 0.05$) among drivers working on HTR. After MR, significant correlations were found between wind speed and heavy eyelid feeling, being prone to forgetting, eye strain, frequent blinking, and between ambient temperature and feeling thirsty. After HTR feeling thirsty, tiredness and difficulty in making decisions correlated with ambient temperature and feeling thirsty with wind speed. Climate conditions can modify the drivers fatigue; therefore, we should be aware of their impact on well-being.

Keywords Climate conditions · Bus drivers · Symptoms of fatigue · Safe driving · Road accident

Introduction

In view of the climate changes related to global warming, the problems of heat exposure and its health consequences for the working population have been gaining interest (Kjellstrom et al. 2017; Błażejczyk et al. 2014). High ambient temperature and humidity were found to have a significant impact on workability, capacity and labour productivity of blue collar workers in outdoor jobs as well as on general work ability in other occupations (Brode et al. 2017). Increased ambient temperature affects also the safety of work. The rate of risky behaviours at work was reported to increase when ambient air temperature was either higher or lower than the thermal comfort conditions (17°–23° WBGT-Wet Bulb Globe Temperature) (Ramsey et al. 1983) determined for the general majority of workers. High ambient temperature is a recognised risk factor of traffic accidents, which was confirmed by the findings from a number of studies conducted across countries of moderate and tropical zones (Morabito et al. 2006; Nofal and Saeed 1997). When ambient temperature was included in the risk factor analysis of fatal traffic accidents, it was found to be more significant than such factors as alcohol intoxication or unfastened seat belts (Zlatoper 1991). It was also associated with the sensation of malaise and increasing drivers fatigue which may be an indirect cause of traffic accidents (Fujii et al. 2015; Noelke et al. 2016).

Drivers' fatigue was reported to be an important risk factor in most traffic crashes. Statistics show that drivers' fatigue accounts for about 10 to 15% of heavy road traffic accidents (RTA). The probability of participating in a traffic accident for a tired driver is eight times as high as for a well-rested driver. In this context, drivers' fatigue and the resulting accidents have been subject to extensive research (Thiese et al. 2015).

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Professional driving is known to be burdened with several risk factors for fatigue, including night time work, long hours of working, improper conditions of relaxation, prolonged time spent in sedentary posture, and a high level of responsibility for the passengers and the cargo. Among these factors, the climate also plays an important role, especially the temperature, as there is a proven relationship between the thermal load and the functioning of the organism (Enander 1989). According to various studies the work capacity reduces as the WBGT values exceeds 26–30 °C (Kjellstrom et al. 2009). The deterioration of physiological functions under environmental conditions exceeding the level of thermal comfort has a significant impact on the drivers' performance and productivity. When scientists compared driving a motor vehicle for a distance of 600 km at conditions of thermal comfort (24 °C) and at heat stress (37 °C), the drivers' performance was found to decrease by 35% on average as the temperature increased. The drivers' performance was measured as the number of errors in driving technique and incidental changes of road lane during driving (Mackie and O'Hanlon 1977).

In the study by Wyon et al., the drivers exposed to heat stress showed increased heart rate and a higher level of fatigue as the time of driving increased (Wyon et al. 1996). In another experiment when the drivers' vigilance during driving at 27 °C was examined (in terms of response to random light stimuli by pressing a button when the light appeared), the number of omitted responses increased by as much as 50% compared to control conditions (21 °C) Hancock and Vasmatzidis (2003). When the drivers' performance at 35 °C and 20 °C was evaluated, the lateral lane position variability was found to be by 13% higher for driving at 35 °C than at 20 °C (Daanen et al. 2003).

The authors demonstrated that the rate of risky behaviours among drivers increased when ambient temperature was higher or lower than that preferred by most workers (Ramsey et al. 1983). The results of analyses of the risk factors for RTA revealed that the highest risk was noted on the days when mean ambient temperature varied from 24.8 to 27.5 °C (Bergel-Hayat et al. 2013). High ambient temperature is a recognised risk factor increasing the RTA rate, which has been documented by the findings of studies conducted in the countries of moderate and tropical climate zones (Morabito et al. 2006; Nofal and Saeed 1997). When ambient temperature was included in the models analysing risk factors for fatal RTA, it was found to be more significant than the driver's alcohol consumption or unfastened seat belts (Zlatoper 1991).

It is not only the temperature, but the weather conditions in general that determine traffic safety (Theofilatos and Yannis 2014). Among the weather characteristics analysed most frequently are fog and rainfall or snowfall. The authors who investigated the risk of RTA as related to precipitation, point out that an impaired visibility due to rainfall is a more significant factor than a decreased wet road surface. This is confirmed by the findings that RTA rate rises only during the rain and not afterwards (Andrey and Yagar 1993). However, driving the vehicle moving on a wet road surface increases the level of the driver's fatigue (Chung et al. 2005).

Studies on the effects of weather conditions on drivers' performance have rarely considered the factor of atmospheric air pressure. In a Korean study, it was included as confounder in the analysis of a correlation between the rate of traumas from RTA and ambient temperature. The findings revealed a positive correlation between atmospheric air pressure and the rate of RTA-related traumas (Lee et al. 2014).

The studies reported above documented the influence of climate conditions on the drivers performance based on measuring physiological parameters and the drivers' reliability and driving quality. However, such studies are not only costly (as they require advanced instrumentation) but also exhaustive for the persons examined. A direct predictor for the driver that his work performance may worsen is the feeling of fatigue he is experiencing. The correlations between the subjective intensity of fatigue and the drivers' performance parameters are so high that the sensation of fatigue indicates an increasing risk of road accident (Smith 2016). The possible associations between climate parameters and drivers' fatigue have not been subject to specific studies thus far. Therefore, we decided to undertake a study to investigate whether and to what extent the particular climate parameters are related to fatigue perception by motor vehicle drivers. The tested hypothesis is that weather conditions (temperature, air humidity, rainfall, wind) affect the development of fatigue, even though the driver performs work in an air-conditioned cabin.

Materials and methods

The study was conducted among 45 city bus drivers in a large urban agglomeration in Poland. The subjects' age ranged 31–58 years (mean 43.7 ± 7.9 lat), and the duration of working as driver varied from 3 to 34 years (14.7 ± 8.6 years). The participants were volunteers from a municipal bus company, with current medical certification qualifying for professional driving.

The drivers were informed about the study objectives and gave their written consent to participate in the project. The study protocol was approved by the Regional Bioethics Commission of the Nofer Institute of Occupational Medicine in Lodz.

Study protocol

The study was performed over the period lasting from July to October 2012. Each driver was examined four times before and after workshift on a monotonous route with a small traffic intensity outside the city center (MR), and before and after workshift on a heavy traffic route in the city center (HTR).

The routes were classified by experts either as ‘easy’ or ‘difficult’ according to the following criteria: routing, traffic intensity and mean number of passengers. On the days of the study, the drivers started working at about 1 p.m., and their working time was slightly over 5 h. This was the so-called short shift which is routine in the driver’s daily schedule and enables a smooth flow of public transport during ‘rush hours’. The study drivers had different routes to cover which was consistent with their individual work schedules. The selection of a short shift for the study was made with a view of standardising the time of the drivers’ examinations.

Local climate assessment

Data on climate conditions (air temperature and pressure, humidity, wind speed, precipitations) on particular study days was collected from a local meteorological station in Lodz, affiliated to the Institute of Meteorology and Water Management, National Research Institute Warsaw, Poland. The data, recorded on hourly basis, for locations in the nearest vicinity of the bus routes driven by the study drivers, made it possible to calculate mean values for particular weather parameters for the working hours of each driver examined. This referred to air temperature and pressure, humidity and wind speed. We used meteorological data, because the cabin temperature was regulated by the drivers themselves as they set up the air conditioning system at the level that was most comfortable to them. The cabin was isolated from the passengers’ area. Therefore, the individually regulated air temperature in the cabin was not a modifying factor of the drivers’ fatigue. The driver has contact with outdoor temperature only during intervals between particular bus rides (about eight 10-min intervals during workday, i.e. 80 min/workshift).

The mean values regarding precipitation were calculated based on its daily total.

Drivers’ fatigue assessment

To measure the level of drivers’ fatigue, the Fatigue Assessment Questionnaire (FAQ) was used. The questionnaire was developed at the Work Physiology and Ergonomics Department of NIOM (Lodz, Poland) based on the inventory of 30 symptoms of fatigue prepared by the Research Committee on Industrial Fatigue, Japan Society for Occupational Health (Yoshitake 1978) and 10 symptoms of visual fatigue. The symptoms were classified into three groups: physical fatigue (17 symptoms: fatigue, feeling thirsty, yawning, tiredness, a need to take breaks, desire to lying down, legs fatigue, drowsiness, hands fatigue, malaise, feeling of heaviness, hand tremor, feeling of confusion in the mind, stiffness, awkwardness, dizziness, difficulty in breathing, uncertainty in maintaining standing position. Mental fatigue (11 symptoms: tendency to irrelevant thoughts, impatience, lack of willingness to work, lack of commitment to work, impaired attentiveness, apathy, being prone to making mistakes, being prone to forgetting, difficulty in thinking, difficulty in concentrating on work, difficulty in decision-making). Visual fatigue (12 symptoms-: frequent blinking, squinting, headache, eye strain, eye pain, lacrimation, heavy eyelids feeling, impaired visual acuity, eye burning sensation, stinging sensation, accommodation problems, blurred vision, glare impression. Each symptom was assessed using a five-point scale: (0) not at all, (1) somewhat, a little, slightly, (2) moderately, (3) fairly much/pretty much and (4) very much. For each driver, the total fatigue score was calculated. This could range from 0 to 160, with a higher score indicating a more intense fatigue. In addition, the participants completed a short questionnaire to elicit information on the length of night sleep, the time of being active before work, and the time and type of meal consumed before the examination.

Statistical analysis

Statistical analysis included Student’s *t* test for independent variables for comparisons of the level of fatigue after driving on the monotonous and heavy traffic routes. Correlation coefficients were calculated to check the relationship between climate parameters and the symptoms of fatigue (significance level $\alpha = 0.05$). For the statistical analysis, Statistica 8.0 was used.

Results

Analysis of the parameters that can modify the level of drivers’ fatigue revealed no significant differences at the start of work shift for the drivers working on the monotonous (MR) or heavy traffic (HTR) bus route. The times of the end of workshift and the overall working time were also very similar for each route. Detailed data are shown in Table 1.

Climate assessment

Data on climate parameters during the drivers’ work shifts are presented in Table 2. The climate conditions did not differ significantly for the MR and HTR. During the study period, no extreme weather conditions were recorded.

Drivers’ fatigue assessment

The total level of fatigue was found to be significantly ($p = 0.045$) higher after driving on HTR (8.49 ± 9.30) than on MR (6.27 ± 7.68). After a working day spent on MR, the drivers reported 5.42 ± 6.43 fatigue symptoms (range 0–21) on average. The number of symptoms was significantly higher, 6.87 ± 6.69 (range 0–24), among drivers working on HTR. The

Table 1 Characteristics of parameters modifying the level of drivers' fatigue (mean, SD, range)

	Monotonous route	Heavy traffic route	*p*
Duration of sleep on the night preceding examination (h)	7.95 ± 1.60 (4.0–12.0)	8.20 ± 1.48 (4.75–12.0)	.470
Start of work shift (h)	12:10–14:57	12:22–14:14	.151
End of work shift (h)	16:55–19:43	17:00–19:35	.480
Duration of work shift (min)	314 ± 41 (183–386)	323 ± 40 (240–400)	.319

rating of the specific symptoms of fatigue after driving on HTR and MR is presented in Fig. 1.

Most of the symptoms were found to be more intense after a working day spent on HTR than on MR; for seven symptoms, these differences were statistically significant. After a workshift on HTR, the most common symptom was a general feeling of fatigue (22 drivers, 48.9%), feeling of thirst (20 drivers, 44.4%), tendency to irrelevant thoughts (20 drivers, 44.4%), yawning (16 drivers, 35.6%) and tiredness (16 drivers, 35.6%). After driving on MR, the most frequently reported symptoms were the general feeling of fatigue (20 drivers, 44.4%), tendency to irrelevant thoughts (18 drivers, 40.0%), feeling thirsty (16 drivers, 35.6%), and legs fatigue (15 drivers, 33.3%).

Among drivers working on HTR, the total fatigue and seven individual symptoms of fatigue correlated with the duration of work shift. In workers driving on MR, the working time was found to have a lower impact on fatigue. After MR shift, only two individual symptoms of fatigue (difficulty in concentrating on work and sleepiness), but not the total fatigue, were found to correlate with the duration of work shift (Table 3).

The ratings for some fatigue symptoms after work shift were found to correlate with specific climate parameters. Much more significant correlations between climate conditions and fatigue could be noted after working on MR than HTR. Detailed data are presented in Table 4. For workers driving on HTR, the feeling thirsty and tiredness correlated with ambient air temperature. A negative correlation was found between these symptoms and the difficulty in decision-making. Moreover, the feeling thirsty negatively correlated with wind speed. None of the symptoms of fatigue correlated with atmospheric air pressure or humidity. After MR workshift, two symptoms were significantly more intense during precipitation: difficulty in thinking ($p = 0.046$) and difficulty in concentrating on work ($p = 0.046$) After HTR workshift, only tendency to irrelevant thoughts ($p = 0.049$) was more intense during precipitation.

Discussion

The findings of the present study revealed that the level of drivers' fatigue was generally low and amounted to about 10% and 13% of the maximum rating for the total fatigue after working on MR and HTR, respectively. The underlying reason could be the relatively short working hours; however, this was found to be less important among drivers working on MR. It can be assumed that longer working hours could be associated with increased fatigue, especially among drivers working on HTR. We presume that relatively low scores for particular symptoms may be attributed also to the good adaptation of the drivers to their job.

The climate conditions as recorded for the study period can be defined as neutral (temperature about 20 °C, moderate humidity, atmospheric air pressure about 993 hPa and no fog) and no extreme weather conditions were noted. The influence of climate on overall drivers' fatigue was rather low but

Table 2 Characteristics of climate parameters on the drivers' working days

Climate parameters	Monotonous route	Heavy traffic route	*p*
Ambient air temperature (°C)			
Mean	19.61	19.94	.789
SD	6.00	5.45	
Median	19.24	20.57	
Range	3.2–31.0	8.6–28.8	
Atmospheric air pressure (hPa)			
Mean	993.2	992.28	.352
SD	5.42	3.8	
Median	994.47	992.03	
Range	983.3–1004.9	982.4–998.8	
Humidity (%)			
Mean	58.48	60.86	.453
SD	16.21	13.48	
Median	57.57	61.14	
Range	32.3–98.6	35.3–93.3	
Wind speed (m/s)			
Mean	3.75	3.81	.822
SD	1.15	1.32	
Median	3.86	3.57	
Range	1.5–7.0	1.6–6.7	
Precipitation (mm)			
Mean	2.24	1.13	.155
SD	4.64	2.35	
Median	0	0	
Range	0–20.9	0–98	

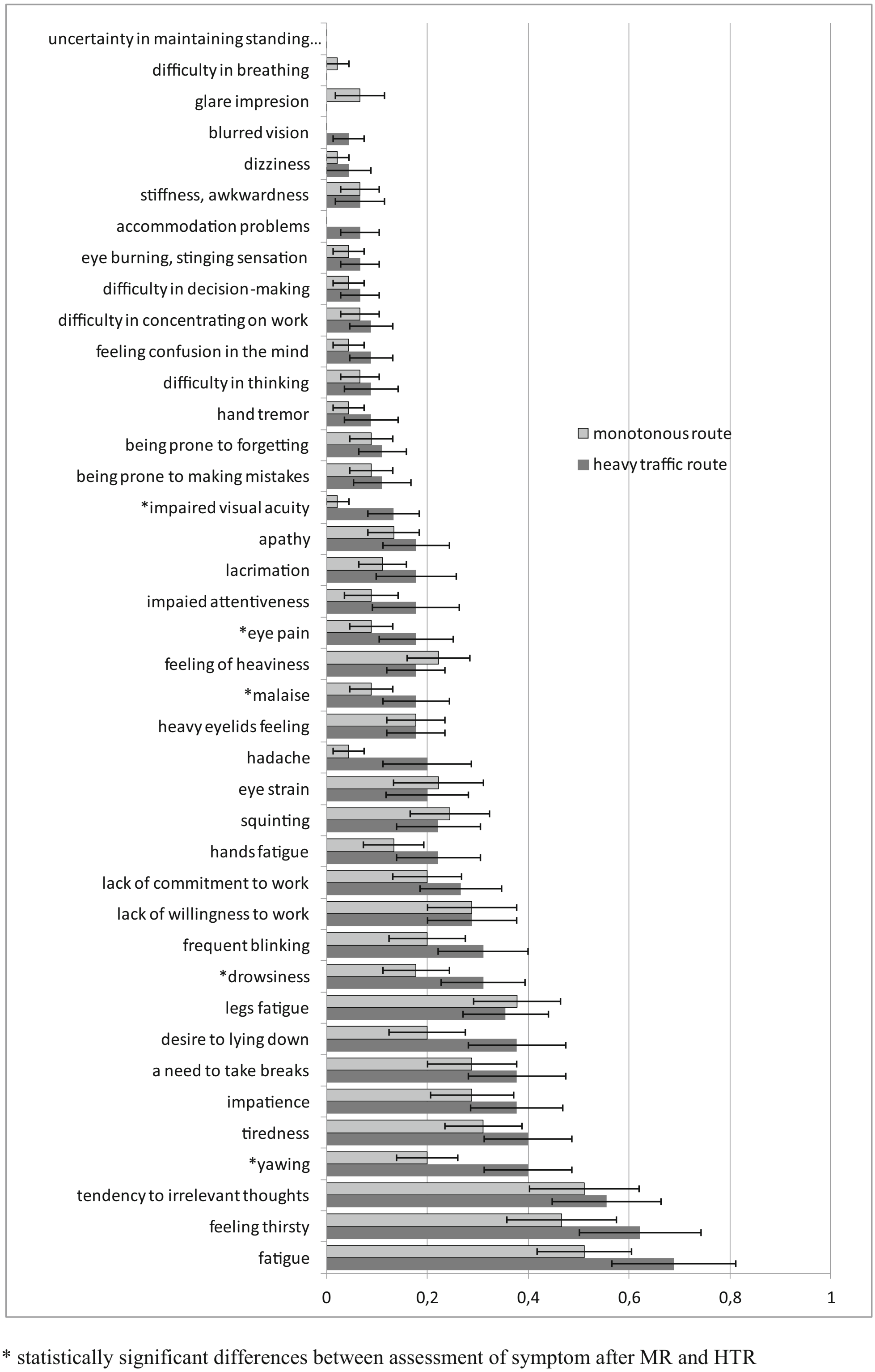

Fig. 1 Ratings for specific fatigue symptoms after driving on monotonous (MR) and heavy traffic (HTR) route (mean and standard error). *Statistically significant differences between assessment of symptoms after MR and HTR

showing a positive correlation with fatigue symptoms. As the weather conditions were becoming more intense and an increase was noted in ambient air temperature, pressure and humidity as well as wind speed, the sensation of the symptoms of fatigue was getting more intense. The fact that the increase in the intensity of fatigue symptoms in response to weather conditions was relatively small, can be attributed to the rather small range of climate variables, and to the high level of competence and job experience of the drivers examined. It has been shown that people with high qualifications and skills in

Table 3 Relationship between duration of work shift for drivers working on a monotonous route (MR) or heavy traffic route (HTR) and drivers' fatigue (*r*—Pearson's correlation coefficient)

Fatigue symptoms	Monotonous route		Heavy traffic route	
	r	*p*	*r*	*p*
Total fatigue			.357	.016
Difficulty in concentrating on work	.302	.044		
Drowsiness	− .488	.001	.326	.029
A need to take breaks			.364	.014
Desire to lie down			.347	.020
Eye strain			.381	.010
Eye pain			.367	.013
Headache			.353	.018
Tiredness			.353	.018

certain activities are capable of maintaining high levels of performance despite the effects of heat stress (Hancock 1986).

In order to assess the current and future potential workplace heat exposures and to develop policies for prevention of heat related health threats and losses of workability, which is an alternative term to work capacity and an input into labour productivity, it is important to have scientifically based heat stress indicators available.

Our study revealed a significant correlation between some symptoms of fatigue and ambient air temperature, wind speed and total rainfall during work shift. In our study, wind speed outside had influence on five symptoms of fatigue after MR. The blowing wind has a direct impact on driving and is perceived by the driver holding a steering wheel as he has to control the vehicle's stability on the road. The wind gust of 5 m/s was found to be equal to 300 N (Reński 2001). According to Bos et al., wind blowing may have also influence on the driver's feeling of comfort and physical wellbeing (Bos et al. 2012).

The incidents of rainfall influenced on difficulty in thinking and difficulty in concentrating on work during driving on monotonous route and tendency to irrelevant thoughts during work on heavy route. In our findings, this was most evident during MR driving. Other researchers investigating the risk of road traffic accidents as related to

Table 4 Relationship between symptoms of fatigue after work and climate conditions during work (statistically significant Pearson's correlation coefficients)

Symptoms of fatigue	Ambient temperature		Wind speed	
	r	*p*	*r*	*p*
Monotonous route				
Feeling of thirsty	0.301	0.045		
Being prone to forgetting			0.452	0.002*
Feeling of confusion in the mind				
Heavy eyelid feeling			0.401	0.006*
Eye strain			0.341	0.022*
Frequent blinking			0.319	0.033*
Impaired visual acuity				
Difficulty in decision-making				
Difficulty in thinking				
Difficulty in concentrating on work				
Number of fatigue symptoms			0.310	0.038*
Heavy traffic route				
Feeling thirsty	0.343	0.021	− 0.297	0.048*
Tiredness	0.321	0.032		
Difficulty in making decisions	− 0.321	0.032		

*Statistical significance

precipitation point out that an impaired visibility due to rainfall is a more significant risk factor than a decreased wet road surface. This is supported by the findings indicating that the accident rate increases only during rainfall and not afterwards (Theofilatos and Yannis 2014, Andrey and Yagar 1993).

In general, the worsening of weather conditions during driving on MR was associated with an intensification of passive fatigue symptoms among drivers (Desmond and Hancock 2001).

With regard to drivers working on HTR, the rising ambient air temperature contributed to more intense sensation of tiredness but did not have much influence on decision-making. Johnson and Kobbrick pointed out that high temperature was associated with deteriorated work performance during monotonous, repetitive and boring tasks, but low impact was noted for the tasks that were interesting or challenging (Johnson and Kobrick 2001). A similar relationship seems to apply to fatigue which is an indicator of a subjective feeling of impaired performance.

Irrespective of the type of bus route the drivers were working, the higher levels of ambient temperature correlated with the feeling of thirst among drivers.

Thirst is an unpleasant feeling and a symptom of insufficient hydration of the organism (Armstrong et al. 2014). However, it can be felt only when the systemic dehydration reaches the level of 1–2% of body mass. At this level, the drivers experience not only malaise and increased fatigue but also concentration problems and deficient performance of tasks that require attention, psychomotor skills and direct memory (Shirreffs et al. 2004; EuroHEAT. Technical report, 2009; Adan 2012). Moreover, body dehydration resulting from heat stress leads to decreased vigour and intensifies the feeling of fatigue (Wetsel 2011). Therefore, the feeling of thirst can be regarded as an indirect indicator of impaired performance which can be particularly significant for the drivers' safety. Appropriate supplementation of liquids is also important for the drivers since water intake increases the potential to reduce sleepiness (Pross et al. 2014). In Poland, there are no specific regulations with regard to drinking limitations for bus drivers, but the drivers themselves tend to limit the drinking as they want to avoid the use of public toilets.

To the best of our knowledge, there have been no studies investigating the impact of climate conditions (except for cabin climate parameters) on the drivers' fatigue and related consequences. The authors assumed that ambient climate conditions may modify the perception of work-related fatigue by the drivers. An example of the influence the external conditions on work performance and the feeling of fatigue are the findings by Bos et al. (2012) which 'reveal subtle environmental influence on psychopathology'. Although these findings concerned a patient diagnosed with recurrent anxiety disorder, one cannot exclude a possibility that they may also apply to healthy individuals.

Moreover, there are also some literature reports on the influence of meteorological environment on human health and wellbeing (Ezekowitz et al. 2013, Wang et al. 2015, Yackerson et al. 2012). Seeing that we have practically no control over the weather conditions to which professional drivers are exposed during work, except for the cabin temperature which the driver can regulate, we should realise what effect they can have on the drivers' performance and wellbeing. The relationship between climate conditions and drivers' fatigue observed in our study may get stronger as the duration of work increases and the fatigue becomes more intense. These preliminary findings point to a necessity for further in-depth studies to elucidate the above.

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Compliance with ethical standards

The study protocol was approved by the Regional Bioethics Commission of the Nofer Institute of Occupational Medicine in Lodz.

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