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Transport route segments and stress effect on drivers

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Abstract. Drivers are expected to drive safely whilst carrying out a variety of complex tasks using physical, sensor, cognitive and psychomotor skills. In this paper, the authors examine the influence of road characteristics and microclimate influence in driver's cabin, on different drivers' performance while accomplishing their daily duties. The authors gave prior emphasis on transport route profiles like pedestrian crossing, road junctions, round about; pulling in and out of each bus stop and other unexpected incidences on driver's attention. The research was held on different drivers on the same transport route and segment of articulation. Work experiences, unfamiliarity of the routes were among the key factors for increasing stress and decreasing drivers' attention. This paper analyse stress factors on drivers during the summer period of driving performance. The core data on microclimate situation in the driver's cabin and the heart rate are preserved through careful measurements on all route segments. The drivers' heart rates are carefully recorded at specific parts in the road to examine how the road characteristics affect driver's behaviour. The influence of route characteristics, the microclimate influence in the drivers cabin, and other complications in transport route on heart rate variations of different drivers is the output of the research findings.

Key words: crossroad; downhill drive; roundabout; transport route; uphill drive.

INTRODUCTION

Number of research papers like Philip, (2005), Patel et al. (2011) and Pogotovkina et al. (2013), has shown on their scientific papers as driving to be a complex task which requires good health and a high level of mental and physical coherence. Similarly, Zalcmanis et al. (2014), have concluded that passenger transportation safety is a priority task and should be given maximum attention to the comfort of drivers and their working conditions including the social legislation related to their respective duties. In this paper, the authors examined the thermal comfort, preferable local microclimate conditions and heart rate variation of city bus drivers of Prague. Drivers pull in and out of bus stops, monitor passengers' behaviour, stick to a strict timetable, provide good service to customers and deal with other unexpected events whilst all of the time driving safely is paramount (Zewdie & Kic, 2015). City bus drivers are also expected to change their driving style to meet the safety demands of the driving environment. For example, compensate for a decrease in attention by reducing speed or refraining from performing risky manoeuvres such as overtaking at a crossroads or at a roundabout. These tasks can cause fatigue, stress and overall burn out. Scientific and professional papers, especially by Lawson (2004), show how different parts of the road/road characteristics can play a significant role in influencing drivers' attention and conclude that driving is a complex task which requires the co-ordination of many skills. Similar conclusions were reported from electrocardiographic studies of London's dense fast-moving traffic which could raise a person's heart beat from 70–85 to 100–140 beats per minute (Mehler et al., 2008; Mehler et al., 2010). Other research relating to driver's safety show how both the geometry of a vehicle (the glazed area) and the interior and exterior material properties can heavily influence the microclimate of the driver's cabin (Zewdie & Kic, 2015).

In this paper the authors show how different parts of the road segments affect the heart rate. Measuring the heart rate is a non-invasive tool for analysing the variations in cardiac rhythm (Kaye et al., 2004). These variations are supposed to be of significance mainly on road junctions (crossroads), at traffic lights, in traffic congestion, in different weather conditions (Lukes et al., 2014), internal driver's thermal conditions in cabin and unexpected events on the road. All the operational activities of the drivers were noted on a separate sheet without the knowledge of the driver. The authors recorded data including characteristics of the route, thermal conditions and heart rate of the volunteer bus drivers. This particular paper investigates the driving performance of Prague's bus drivers en route, and how drivers' heart rate affected the results on the bus 107.

MATERIALS AND METHODS

The authors performed the research on three Karosa KbN B941 City Buses of the same model, a Czech brand which is commonly used in the city's transport system. All buses are the property of the district of 'Repy', Prague Urban Public Transport. The authors compared the weight, height, oxygen content of their blood (before and after their drive), the drivers' age and the number of years spent working as a City bus driver. Although, the research was confidential, we took into consideration the background of each and every individual driver. The first driver (A) is twenty-five years old (performed the test in August 2014), had his driving license for five years and drove ten thousand kilometres or more annually. The second driver (B) is forty-nine years old (performed in August 2014) and has fifteen years of working experience as a city bus driver. The third driver (C) is forty-five (performed in July 2015) and has fourteen years' of experience (Table. 1). The drivers' selection was based on the age, weight, and height and work experience in the company they work for. The youngest driver (A) was nearly 50% younger than the other two drivers (B and C). Work experience at the company of driver (A) was nearly a third of the experiences compared to drivers B and C. This selection was made to compare two age categories, i.e. 25 years and nearly 50 years old drivers.

All participants of the research were volunteers with the Prague transport management for two summers (of relatively mild climates – August 2014 and July 2015). Data was collected on each individual driver. The time and route was selected, so that every driver had very similar weather and driving conditions. The measurements were first taken from station 'Za sokolovnou' and ended at the 'Dejvicka' station and then also for the return journey. The measurements were taken on the same route ten round trips by each driver.

Table 1. General information on research conducted drivers

Driver	A	B	C
Age (year)	25	49	45
Weight (kg)	80	130	94
Height (cm)	170	180	185
Work experience (year)	5	15	14
O_2 content in blood (%)*			
-before driving	96	90	92
-after driving	92	86	83
Pulse (min^{-1})*			
-before driving	67	98	85
-after driving	71	99	89
Status (-)	single	divorced	married
Activity (-)	cycling	not willing to tell	musician

* - obtained through measurement

The method of collecting the data was identical for all three drivers. The road numbered 241 was used for the research and is classified as a 2nd category road by EU standards (Fig. 1). It has an average elevation of 5.1 to 5.3% and has a maximum height above sea level of 275 m at the top and 181 m at the lower part of the road (Fig. 2). It is the artery communication route that connects the suburban vicinities adjacent to the capital city transport network and is a main route leading to the city centre and the surrounding areas of the capital. From the metro station Dejvicka, the bus line 107 transports students and employees to the university which makes up to a total of 25,000. Similar bus serves as a transport mode for Suchdol inhabitants and visitors.

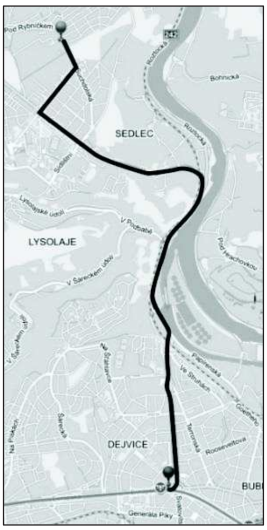

Figure 1. Line 107 road map.

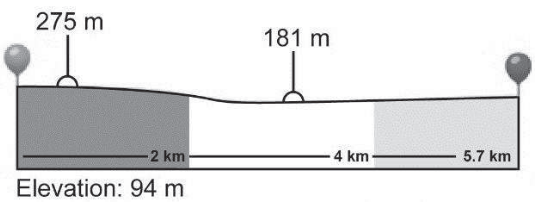

Figure 2. Line 107 road profile.

The route for all three drivers starts at station Za Sokolovnou in Suchdol, Prague 6 and goes to the terminal Vitezne Namesti at the Dejvice metro station, covering a distance of 5.9 km including the return trip the total travelled is 11.78 km. This is performed ten times so the total distance travelled by each driver is 118 km. The route was chosen based on the roads' characteristics. A total of nine data recording points were selected and are shown in more detail on Table 4. At each reference point, the average heart rate has been registered and calculated.

MEASURING INSTRUMENTS

For the actual measurement, the driver should put on a sensor (Polar RS800CX) around the body and computer device on the wrist of the driver to record the heart rate variability (HRV). The package of the measurement instrument consists of four parts brand of Polar. The Polar RS800CX is a computer which displays and records the heart rate and other data like position and velocity during driving examination; Polar wear link W.I.N.D. a transmitter, sends the heart rate signal to the computer. It includes connector and strap; CD-ROM which includes software and a complete user manual for the RS800CX computer.

The other accessory to RS800CX computer is Polar s3 stride sensor W.I.N.D. Polar G3 GPS sensor. G3 sensor provides all the data on velocity and distance covered by the vehicle on the basis of income and evaluating GPS satellite signals. The position of the sensor is constantly compared by at least with four visible satellites. The values the sensor G3 transmitted through wireless radio frequency of 2.4 GHz sent out for evaluation in receiver up to a distance of 15 m. Relevant data were collected from measurement devices which are installed on the body and wrist of the performing driver. Data detected (heart rate of the driver, position and velocities of the bus) are stored in Polar RS800CX are transformed through infra port to a personal computer for further processing and analysis.

The Czech government health protection regulation determines the conditions for the protection of health related to light manual work such as driving under normal operating conditions. Under this regulation, for particular metabolic energy output 81–105 W m^{-2}, the recommended operating temperature is 20 ± 2 °C and relative humidity to be 30–70%. Thermal state of the internal environment can be described by applying the index of temperature and humidity (THI). This index is widely used to describe the heat stress, and it is also a key indicator of the environmental conditions of stress.

Data on the microclimate conditions in the bus driver's cabin were collected from measurement devices which are installed on the dashboard of the bus. The thermal comfort in the space was continuously measured by globe temperature (measured by globe thermometer FPA 805 GTS with operative range from –50 to +200 °C with accuracy ± 0.01 K and diameter of 0.15 m) together with temperature and humidity of surrounding air measured by sensor FH A646-21 including the temperature sensor NTC type N with operative range from –30 to +100 °C with accuracy ± 0.01 K, and air humidity by capacitive sensors with operative range from 5 to 98% with accuracy ± 2%. The concentration of CO_2 was measured by the sensor FY A600 with operative range 0–0.5% and accuracy ± 0.01%. All data were measured continuously and stored at intervals of one minute to the measuring instrument ALMEMO 2690–8 during the measurement.

RESULTS AND DISCUSSION

Principal measurement results of heart rates of all three bus drivers, and the conducted vehicles are evaluated and summarized on Figs 3–6. Fig. 6 contains the result the combination (round trip) of three drivers' average heart rates at the monitored reference points, for nine selected variables. The mean values including standard deviation were calculated from the results of measurements for each of parameters. The obtained results of measurements were processed by Excel software and verified by statistical software Statistica 2013. The average values including standard deviation were calculated from the results of measurements for each of external and microclimatic parameters: external temperature t_e, external relative humidity RHe, internal temperature t_i, internal globe temperature t_g, internal relative humidity RHi, THI, BGHI and concentration of CO_2.

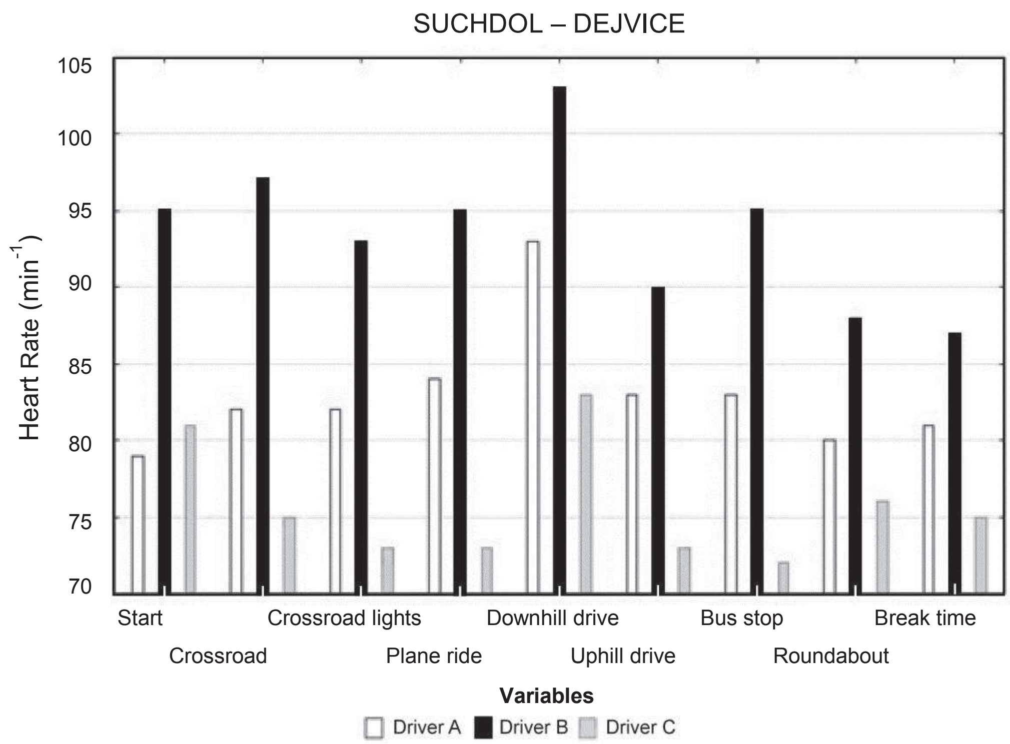

Figure 3. Bar/Column chart of heart rate of different drivers from Suchdol to Dejvice.

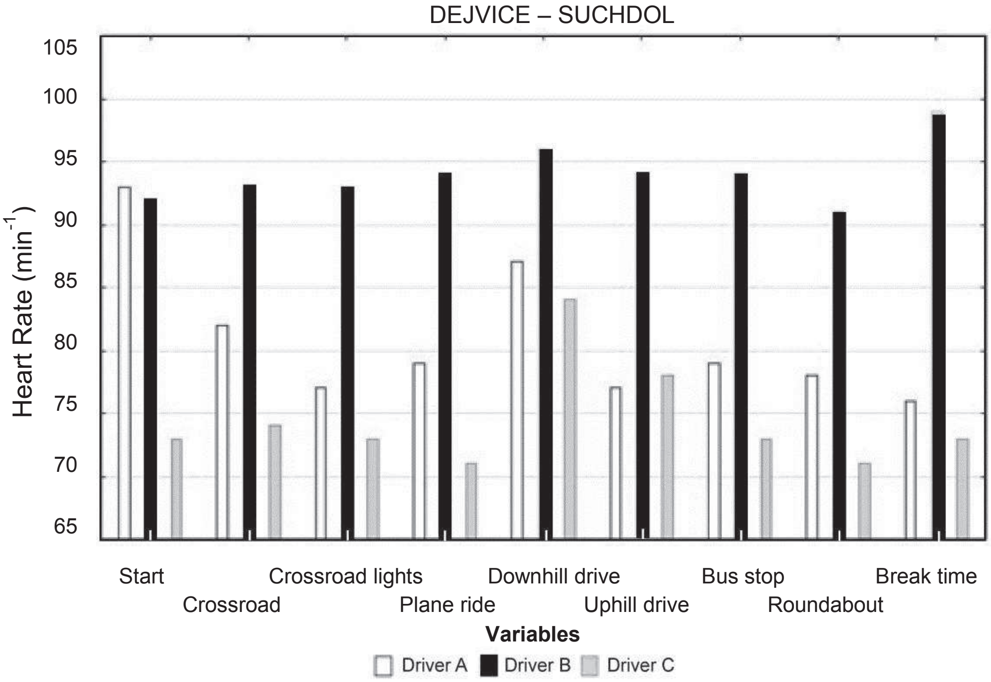

Figure 4. Bar/Column chart of heart rate of different drivers from Dejvice to Suchdol.

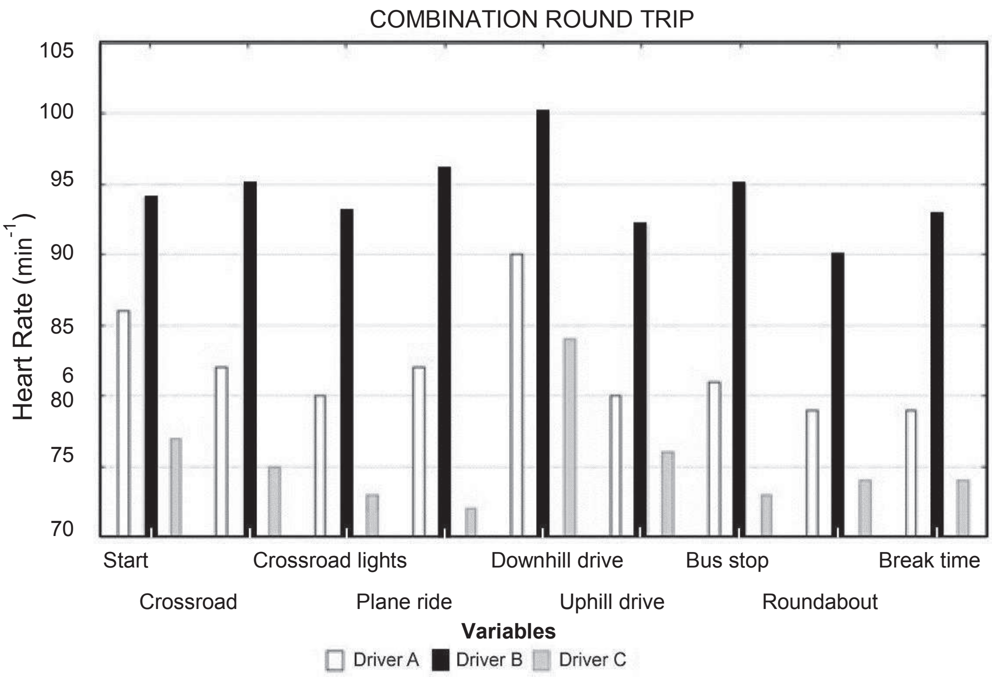

Figure 5. Bar/Column chart of heart rate of different drivers round trip.

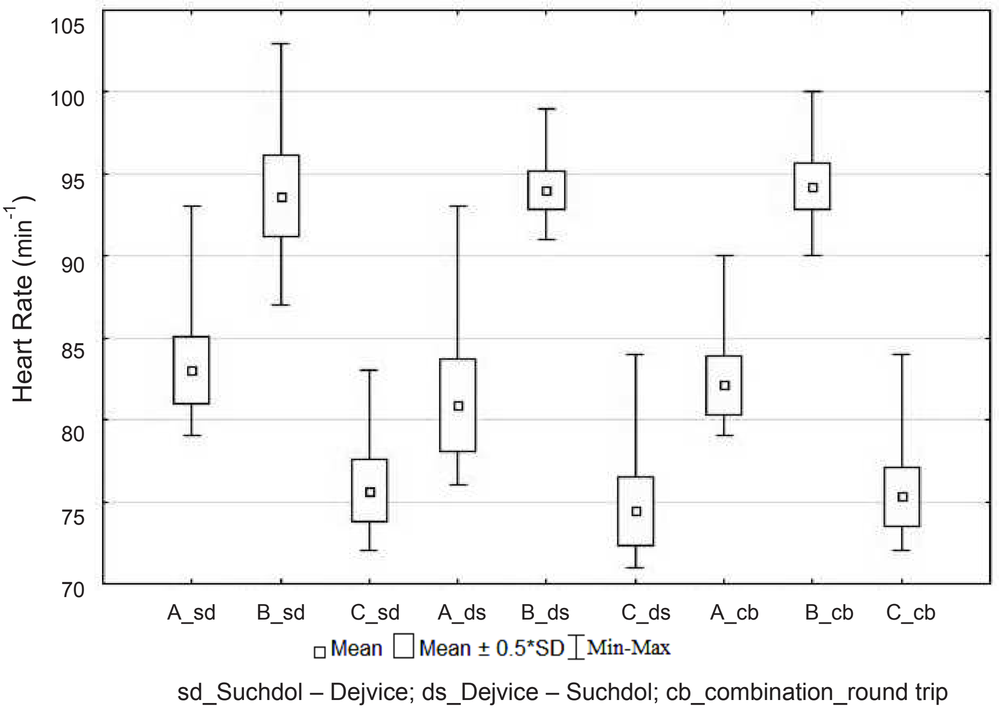

Figure 6. Box and Whisker plot of different drivers heart rate from Suchdol – Dejvice, Dejvice – Suchdol and round trip.

The results of the measurement microclimate in the bus cabin during the morning are presented in Table 2, afternoon measurements are in Table 3. Examples of the course of the THI and BGHI are calculated from the internal parameters measured during the morning and afternoon measurements in the bus cabin.

For the analysis, descriptive statistical values compile number of variables, mean, standard deviation; minimum and maximum heart beats are selected as shown on Table 4. Figs 3–6 compile the results of the final descriptive statistics for all drivers graph representation of results.

Table 2. Indoor parameters in cabin of bus during the morning

Parameter	t_e	RH_e	t_i	t_g	RH_i	THI	BGHI	CO_2
Units	°C	%	°C	°C	%	-	-	%
Mean value	15.4	53.6	22.22	24.19	39.8	67.3	69.7	0.041
Standard devia.	0.5	3.4	0.62	1.25	1.3	0.68	1.5	0.009
Minimum	13.9	48.7	20.65	20.69	36.1	65.54	65.4	0.033
Maximum	16.4	60.8	23.91	26.57	44.5	68.96	72.4	0.075
Median	15.8	51.2	22.14	23.97	39.8	67.18	69.5	0.037

Table 3. Indoor parameters in cabin of bus during the afternoon

Parameter	t_e	RH_e	t_i	t_g	RH_i	THI	BGHI	CO_2
Units	°C	%	°C	°C	%	-	-	%
Mean value	19.5	33.6	29.98	29.88	22.1	73.7	73.7	0.034
Standard devia.	0.4	0.51	2.72	1.30	2.8	2.3	1.5	0.002
Minimum	18.6	32.9	25.95	26.73	14.0	70.1	70.3	0.033
Maximum	20.3	36.0	38.99	33.12	27.3	81.3	77.7	0.050
Median	19.7	33.3	29.0.	29.52	22.5	73.3	73.7	0.033

Table 4. Influence of route segments on drivers heart rate round trip drive

		Drivers HR, min^{-1}		
		A	B	C
Segment	No. of segments	HR ± SD	HR ± SD	HR ± SD
S-D	9	83 ± 4	94 ± 5	76 ± 4
D-S	9	81 ± 6	94 ± 2	74 ± 4
S-D-S	18	82 ± 4	94 ± 3	75 ± 4
Start	2	86 ± 5	94 ± 5	77 ± 4
Crossroad	10	82 ± 4	95 ± 4	75 ± 3
Crossroad with light	8	80 ± 4	93 ± 3	73 ± 3
Plane ride	12	82 ± 5	96 ± 2	72 ± 4
Downhill drive	4	90 ± 4	100 ± 2	84 ± 2
Uphill drive	4	80 ± 5	92 ± 4	76 ± 4
Bus stop	20	81 ± 4	95 ± 3	73 ± 3
Roundabout	4	79 ± 3	90 ± 4	74 ± 2
Drivers break	2	79 ± 3	93 ± 2	74 ± 2

Fig. 3. Represents Suchdol – Dejvice drive. The minimum measured heart rate for driver A was 72 min^{-1}. The downhill drive segment shows the highest 93 min^{-1} or A = 93 ± 5 and the increase demonstrates 129%. Similarly, the lowest heart rate for driver B was 82 min^{-1}. The same segment, downhill drive, indicates the highest heart rate 103 min^{-1} or B = 103 ± 5, which means the highest increase to be 126%. Similar pattern was observed on driver C as the smallest heart rate being 64 min^{-1} and the highest 83 min^{-1} or C = 83 ± 6 at downhill segment and increase in 130%. The heart rates of all three drivers of are showing an increase in the downhill stretch drive probably caused by physiological stress.

Fig. 4. Represents the reverse drive from Dejvice – Suchdol. For subsequent analysis procedures are like the previous drive. The only difference is the bus ride was in the opposite direction, i.e. Dejvicka – Suchdol. Driver A with minimum heart rate 71 min^{-1} was recorded to maximum to be 93 min^{-1} or A = 93 ± 5 right at the beginning of the drives with the increase of 131%. Similarly, driver B with the smallest 82 min^{-1} and maximum 96 min^{-1}, B = 96 ± 4 had the increase of heart rate by 117%. The third driver C had its lowest to be 65 min^{-1} and the highest 84 min^{-1}. C = 84 ± 4 has increased by 129%.

Fig. 5. Shows the result of the combination for both driving directions. The graph is compiled out of ten complete round trips by all three drivers. It is explained by the fact that, it is classified from Suchdol to Dejvice (Fig. 4), and from dejvice to suchdol (Fig. 5) drive. The minimum heart rate for driver A is again 72 min^{-1} and the maximum

90 min^{-1}, or A = 90 ± 5 with the increase of 125% at the downhill segment. It is clearly shown that driver B has the highest heart rate 100 min^{-1} with the increase of 122% at the same downhill segment. Driver C scores the maximum of 84 min^{-1} with the increase of 129%.

Fig. 6. Represents Box and Whisker plot of different drivers heart rate from Suchdol – Dejvice (sd), Dejvice – Suchdol (ds) and round trip as combination (cb). The mean, mean and standard deviation, the mean with minimum and maximum heart rate range graph. From the graph it is clearly seen that the highest positive standard deviation range is at driver A_sd , A_ds and A_cb. This finding probably confirm the age, physical fitness and sports activities of the driver.

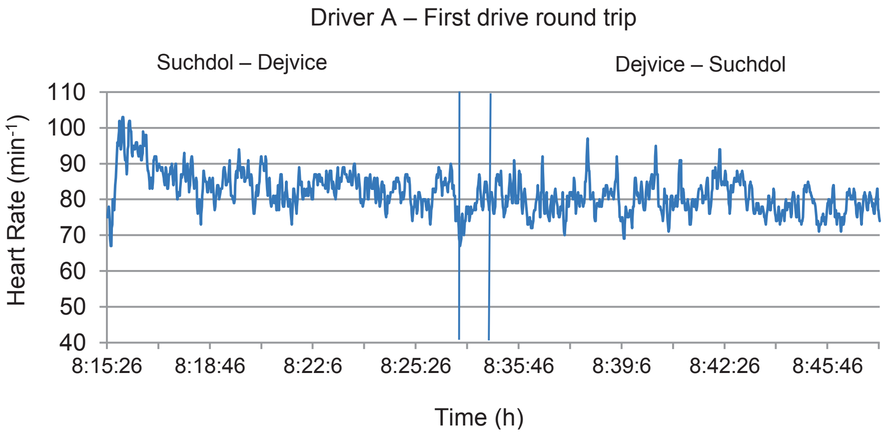

Figure 7. Behaviour of the function of the Heart rate the drivers first drive Suchdol – Dejvice round trip (driver A).

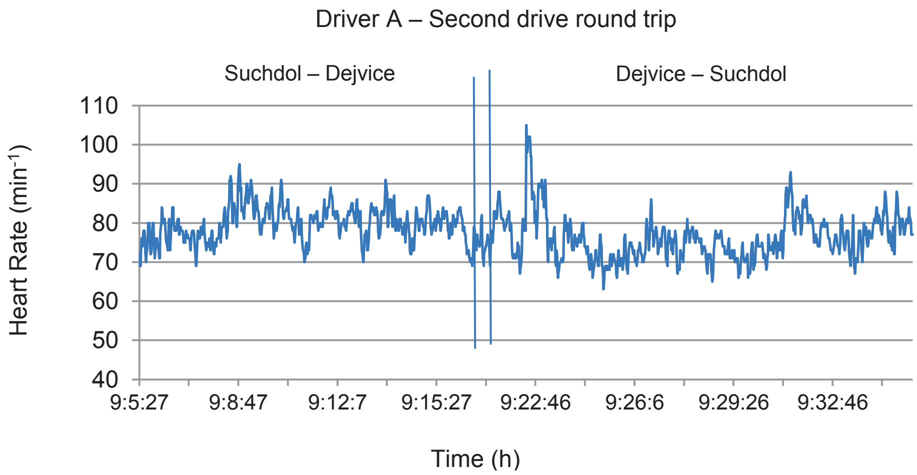

Figure 8. Behaviour of the function of the Heart rate the drivers second drive Suchdol – Dejvice round trip (driver A).

Figs 7, 8. Demonstrate behavioural functions of the heart rate of the driver A. From both figures, it is clearly seen that at every drive the heart rate could differ due to unexpected circumstance like fixing measuring device (Fig. 7) Suchdol – Dejvice drive, radio call from the dispatcher (Fig. 8) Dejvice – Suchdol drive. Driver A had the highest heart beat 103 min^{-1} at the morning drive at 8:15 (Fig. 7), respectively 105 min^{-1} at 9:22 (Fig. 8).

Tables 2, 3 represent the Indoor parameters in cabin of bus during the morning and Indoor parameters in cabin of bus during the afternoon. Thermal state of the internal environment can be described by applying the index of temperature and humidity (THI). This index is widely used to describe the heat stress, and it is also a key indicator of the environmental conditions of stress, temperature.

CONCLUSIONS

This study demonstrates that some drivers exhibit changes in heart rate variability depending on the feature of route segments. Significant influence of the increase of heart beat which was observed on all drivers was a downhill route segment. This could be caused by vehicle breaking leading to stress effect. Radio communication from dispatchers, cell phone calls, and ill-disciplined passengers etc. could be among causes for the increase or heart rate disorders. Physical fitness, social comforts increase the capacity of withstanding variable stress which might be different to each driver. Driver C had low heart rate and factors could be a settled and better social life and may be better health dispositions. Driver B scored the highest heart rate on all variables. Possible factors could be health factors such as age, weight and other social discomfort, etc.

All drivers had different heart rate increases at different segments. Driver A scored the highest increase in percentage at the downhill drive (125%) and the start point (119%). On driver B, it was observed the increase at five segments; plane ride (117%), crossroad (116%), bus stop (116%), crossroad with light (113%), and the heights were the downhill drive (122%). Driver C also features the increase in percentage on four segments; downhill drive (129%), start position (118%) and uphill drive (117%).

The internal conditions in the cabin of bus are strongly influenced by solar radiation, especially at a larger proportion of cabin glazing. Based on the result of the morning measurements in the bus, higher temperatures have occurred, for example global temperature t_g from 20.7 °C to 26.6 °C. The internal temperature t_i rose from 20.7 °C to 23.9 °C. This indicates that the influence of solar radiation has increased rapidly compared to the internal temperature, which is against regulation in relation to the directive on health supervisor (Government Regulation 361/2007 of Czech Republic, 2007).

Measurement evaluation applying the THI and BGHI indexes also reveals the major influence of radiation. E.g., the mean value of the THI is 67.3 and the BGHI mean value 69.7. In the lower outside air, temperatures can reduce the influence of solar radiation by adequate ventilation of the cabin. In the higher outside air, temperatures can maintain the recommended air temperature inside only using the cooling (air conditioning) of air. Drivers are recommended to ventilate sufficiently even in colder outdoor conditions to let in the fresh air (O_2) and exhaust the polluted air (CO_2 and odours). Based on the results of the measurement, a slightly higher concentration of CO_2 (0.075%) has occurred.

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