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Full Length Research Paper

Evaluation of the physiological data indicating the dynamic stress level of drivers

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Bio-signal recordings that reflect the operating conditions of the physiological systems provide several useful metrics to determine the dynamics of internal states in human body. In this context, this study is aimed to identify the useful metrics indicating the real-time stress level of drivers. Totally 10 of drivers' bio-signal datasets obtained from MIT-BIH PhysioNet Multi-parameter Database were used to quantify the stress level of drivers. Each dataset includes several bio-signal recordings gathered from drivers during the drives conducted in a set path where 3 different levels of stress likely occur through over 20 miles of open roads. The recordings have markings indicating the time intervals between the driving segments corresponding to a number of city and highway driving periods with initial and final rest periods. Evaluations have been completed by using the available segment based arrays of instantaneous heart rate (IHR), hand based skin conductance (HSC), foot based skin conductance (FSC) and electromyography (EMG) signals. For further evaluations, the segment based data arrays including instantaneous respiratory rate (IRR) and average number of contractions/minutes (CPM) have been derived from the respiratory and EMG signals, respectively by using a peak detection algorithm. Statistical comparisons using the overall mean and mean values of the IHR, HSC, FSC, EMG, IRR and CPM data arrays showed that with an optional exception of IRR all of these metrics can be identified as useful parameters in the future car technology to determine the dynamic stress level of drivers.

Key words: Driving stress of drivers, dynamic stress level, electromyography, heart rate, respiration rate, skin conductance.

INTRODUCTION

Autonomic nervous system primarily involves emotional responses and controls the smooth muscles, heart muscle and secretion of the glands in human body (Ahuja et al., 2003). As a result of this fact, bio-signal recordings reflecting the operating condition of the physiological systems including the circulatory, respiratory, muscular and endocrine systems can provide useful metrics representing the dynamics of the internal states in human body. Therefore, it would be expected that the data reflecting task related internal states can be derived from those recordings. In this context, they can be used to evaluate the various task related physiological status of humans (Helander, 1978; Veltman and Gaillard, 1996; Hankins and Wilson, 1998; Niskanen et al., 2004; Lewis et al., 2007). For a driving process, task related data can be derived from physiological recordings that can be collected continuously without interfering with the driver's performance. Information obtained by this way can provide a continuous measure to determine how different road and traffic conditions affect the drivers.

This information can also be used automatically by adaptive systems and non-critical in-vehicle information systems such as radios, cell phones, and on-board navigation aids, to help the driver cope with stress (Burns and Lansdown, 2000). On the other hand, understanding the driver frustration is one of the key areas listed by international research groups for improving the Intelligent Transportation Systems (ITS). Thus, increasing use of on-board electronics and in-vehicle information systems has made the evaluation of driver task demand an area of increasing importance to both government and industry (Noy, 2001). In this context, the protocols to measure the driver workload have been developed using eye glance and on-road metrics. However, these have been criticized as very costly and difficult to obtain. In addition, uniform heuristics designed to provide an upper limit for the total time allowed for completing a navigation system task, do not provide flexibility to account for changes in the driver's environment (NHTSA, 2000). An alternative study in ITS context has been realized by recording the real-time physiological data from the drivers during a number of driving realized in the open roads (Healey and Picard, 2005).

In the study conducted by Healey and Picard (2005), the electrocardiography, electromyography, hand/foot based skin conductance, and respiration signals are recorded continuously while drivers followed a set route through the open roads. Although stressful events related to road and traffic conditions could not be specifically controlled on the open road, obtained data related to different drives were marked to show the initial rest, highway, and city driving periods that were assumed to produce low, medium, and high levels of stress, respectively. Then, this assumption was validated by using the features calculated at 1 s intervals throughout the entire drive. Obtained results show that skin conductivity and heart rate metrics are most closely correlated with driver stress level (Healey and Picard, 2005). Besides the heart rate and skin conductivity, additional parameters reflecting the dynamic stress level of the drivers such as amplitude of electromyography and instantaneous respiratory rates could be derived from the bio-signal recordings without any other hardware implementation. Furthermore additional parameters can improve the accuracy of results on real time stress evaluations. At the same time, advances in the on-board electronics and in-vehicle information systems make it easier to retrieve new types of bio-signal recordings with each passing day.

In this study, it is aimed to contribute the studies on ITS by using the physiological signals that are available from MIT-BIH Multi-parameter Database (PhysioNet, 2010). The dataset, used in this study, was contributed to PhysioNet (2010) by its creator, Jennifer Healey (2005). It contains a collection of multi-parameter recordings from healthy volunteers, taken while they were driving on a prescribed route including city streets and highways in and around Boston, Massachusetts.

MATERIALS AND METHODS

In total, 27 drives were completed in the Healey and Picard's (2005) study. However, by using the features calculated from video recordings at 1 s intervals throughout the entire drive, only for the 16 of total 27 drives it was validated that the rest, highway, and city driving periods produce the low, medium, and high levels of stress, respectively (Healey and Picard, 2005). In this study, totally 10 group of those 16 recordings could be used for evaluations of driver's stress levels. For that reason, remaining 6 datasets may not be helpful to find the correct markings and to determine the transient times between the driving segments of recordings. Evaluations have been made by the comparisons of the overall means, and mean values of the available segment based arrays of electro-cardiograph (ECG) derived instantaneous heart rate (IHR), hand based skin conductance (HSC), foot based skin conductance (FSC) and electromyography (EMG) signals. In addition, segment based data arrays including instantaneous respiratory rate (IRR) and average number of contractions/min (CPM) have been derived from respiratory (RESP) and EMG signals, respectively to improve the results of the evaluations.

Materials

Healey and Picard (2005) used four types of physiological sensors during their experiments. These sensors were connected to a FlexComp (1994) analog-to-digital converter, which kept the subject optically isolated from the power supply. The FlexComp (1994) unit was connected to an embedded computer in a modified car. The ECG electrodes were placed in a modified lead II configuration to minimize motion artifacts and to maximize amplitude of the R-waves. Instantaneous heart rates have been derived by using the algorithm depending on the R-wave peak detection (Moody, 1985). The EMG electrode was placed on the trapezius (schoulder) muscle (Cacioppo and Tassinary, 1990). The skin conductance was measured at two locations: on the palm of the left hand using electrodes placed on the first and middle finger and on the sole of the left foot using electrodes placed at each end of the arch of the foot. Respiration was measured through chest cavity expansion using an elastic Hall-effect sensor strapped around the driver's diaphragm. Figure 1 shows the general placement of physiological sensors with respect to the automotive system (Healey and Picard, 2005). Each signal was sampled at a rate appropriate for capturing the information contained in the signal constrained by the sampling rates available on the FlexComp system.

The ECG was sampled at 496 Hz, the skin conductivity (SC) and RESP signals were sampled at 31 Hz, and the EMG was sampled at 15.5 Hz after first passing through a 0.5 s averaging filter. The signals were collected by embedded computer in the testing car (Healey and Picard, 2005). Figure 2 shows an example driver bio-signal dataset of 'drive05' obtained from MIT-BIH Multi-parameter Database (PhysioNet, 2010), indicating the driving segments of whole driving process. Each bio-signal dataset includes original 496 Hz sampled ECG signal, 15.5 Hz sampled EMG signal, 31 Hz sampled RESP signal and 31 Hz sampled SC signals that are HSC and FSC. In addition, an IHR signal derived from ECG signal with 31 Hz sampling frequency has been included in each bio-signal dataset (PhysioNet, 2010).

The recording given in Figure 2 has been arranged from original recording to indicate the driving segments along the whole driving process. Therefore sampling details of the 'drive05' bio-signal dataset do not appear in Figure 2. In order to show the recording details, a 10 s close up of original 'drive05' bio-signal dataset has been shown in Figure 3.

The time intervals of the 7 driving segments related to the available drivers' bio-signal datasets used in this study are given in Table 1. Total driving times have also been shown for each driving in Table 1.

Methods

The mean and standard deviations related to the segment based data arrays have been calculated for available IHR, HSC, FSC and EMG signals obtained from 10 of the drivers' bio-signal datasets. Let $x(t)$ represents the signal to be concerned, and $x_s(t)$ be any segment based data array of the signal x. If x_s has Nx_s number of measured samples through the time interval ΔTx_s of the segment, then the mean of the segment based data arrays are calculated as follows

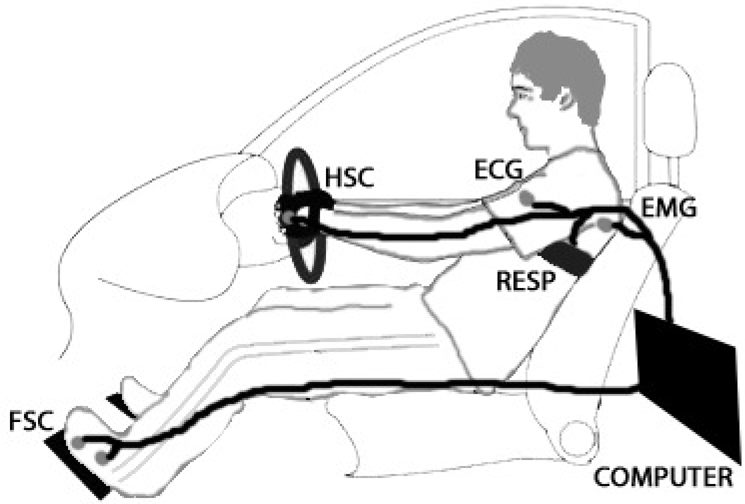

Figure 1. General placement of physiological sensors (Healey and Picard, 2005).

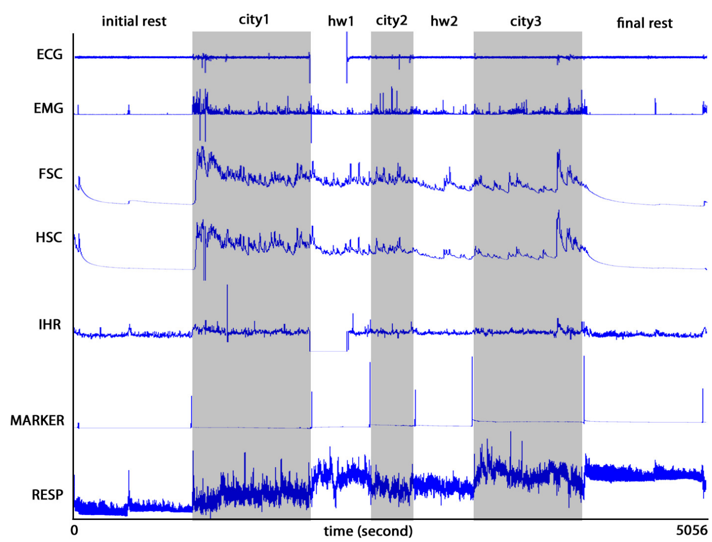

Figure 2. An example driver bio-signal dataset obtained from PhysioNet (2010) website.

$$\mu_{x_s} = \frac{1}{N_{x_s}} \sum_{n=1}^{N_{x_s}} x_n \tag{1}$$

Here, n represents the sample index and μ_{xs} is the mean of the segment based data array x_s. Corresponding MATLAB (The Mathworks, 2007) command calculating the mean of the segment based data arrays are given as follows:

$$\mu_{x_s} = mean(x_s) \tag{2}$$

Similarly, standard deviation of the segment based data arrays are calculated by the square root of the variance given as the following equation:

$$\sigma_{x_s} = \sqrt{\frac{1}{N_{x_s}} \sum_{n=1}^{N_{x_s}} (x_n - \mu_{x_s})^2} \tag{3}$$

Here, σ_{xs} is the standard deviation (SD) of the segment based data array x_s. Corresponding MATLAB (The Mathworks, 2007) command calculating the SD of the segment based data arrays are given as follows:

$$\sigma_{x_s} = std(x_s) \tag{4}$$

Obtained mean and SD values related to the segment based data

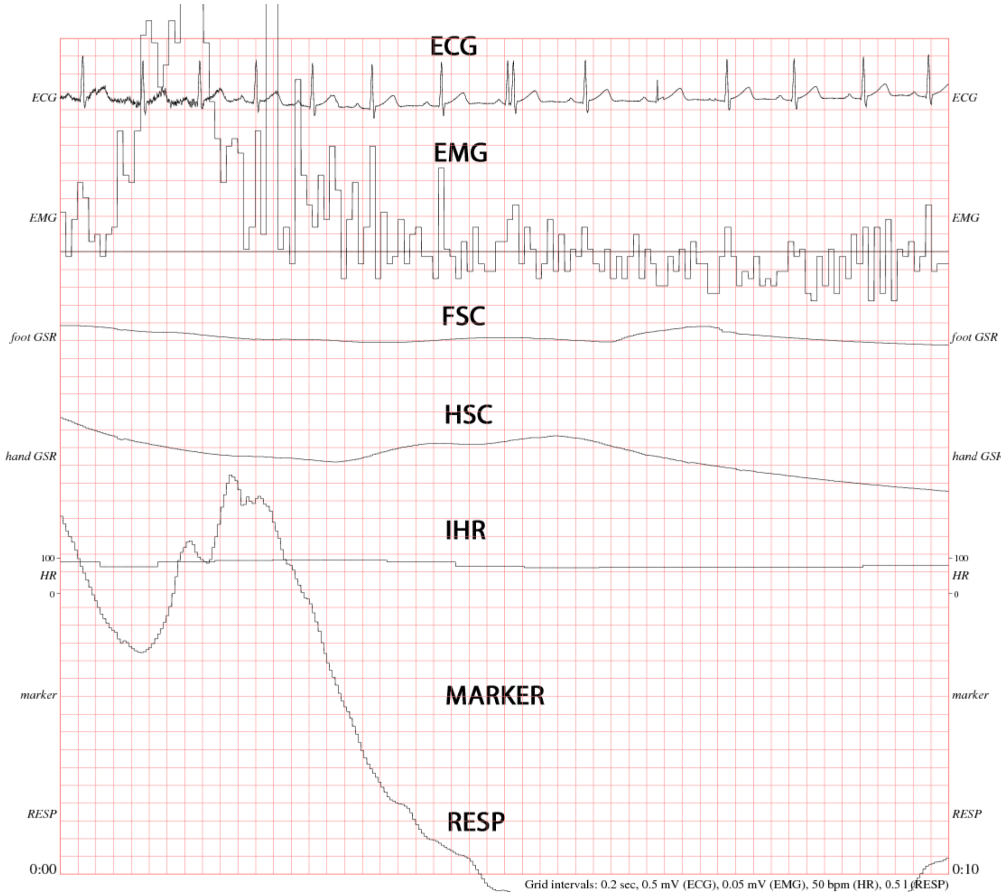

Figure 3. A 10-s close up of original 'drive05' bio-signal dataset.

Table 1. Time intervals of the 7 driving segments of available bio-signal datasets.

Rec.Name	Driving period (min)							Total rec. time (min)
	Initial rest	City1	Hw1	City2	Hw2	City3	Final rest	
Drive05	15.13	16.00	7.74	6.06	7.56	14.96	15.78	83.23
Drive06	15.05	14.49	7.32	6.53	7.64	12.29	15.05	78.38
Drive07	15.04	16.23	10.96	9.83	7.64	10.15	15.03	84.87
Drive08	15.00	12.31	7.23	9.51	7.64	13.43	15.07	80.19
Drive09	15.66	19.21	8.47	5.20	7.06	13.21	NA	68.82
Drive10	15.04	15.30	8.66	5.27	7.04	12.06	14.79	78.15
Drive11	15.02	15.81	7.43	7.15	6.96	11.72	14.99	79.08
Drive12	15.01	13.41	7.56	6.50	8.06	11.68	15.01	77.23
Drive15	15.00	12.54	7.24	5.99	6.82	12.12	15.00	74.70
Drive16	15.01	16.12	7.14	5.12	6.81	13.91	NA	64.10

NA: Not available

arrays of available 10 drivers' bio-signal datasets are given in Tables 2, 3, 4 and 5, respectively for the IHR, HSC, FSC and EMG signals. In Table 2 the mean and SD values of the segment based IHR arrays are given by the unit of beat per minute (bpm).

In Tables 3 and 4 the mean and SD values of the segment based HSC and FSC arrays are given by the unit of micro-Siemens (µS). The statistical data given in Tables 2, 3 and 4 were also evaluated in the Healey and Picard's (2005) study. However, additional 3 types of new data arrays have been produced in this study for further evaluations. These data arrays represent the amplitude variations in EMG recordings, instantaneous respiratory rates (IRR) in RESP signals and average number of contractions per minute (CPM) of trapezius muscle in EMG recordings, related to the observed drivers. For this aim, IRR and CPM data arrays have

Table 2. Segment based mean and SD values of IHR arrays.

Rec.Name	Mean IHR; Mean instantaneous heart rate (bpm ± SD)						
	Initial rest	City1	Hw1	City2	Hw2	City3	Final rest
Drive05	64.9 ± 7.0	78.5 ± 9.8	74.5 ± 10.1	76.8 ± 6.9	72.3 ± 4.6	77.5 ± 8.8	65.8 ± 7.4
Drive06	81.8 ± 8.4	104.8 ± 11.9	90.0 ± 10.1	99.8 ± 9.5	86.6 ± 10.3	93.2 ± 11.2	78.6 ± 9.8
Drive07	71.8 ± 7.0	79.9 ± 7.6	74.4 ± 6.2	77.2 ± 6.6	72.0 ± 4.1	76.7 ± 8.0	69.9 ± 9.5
Drive08	63.4 ± 7.2	72.6 ± 12.3	66.9 ± 10.5	71.7 ± 13.1	66.1 ± 11.5	74.5 ± 21.2	63.5 ± 12.5
Drive09	66.2 ± 8.6	72.0 ± 9.1	71.2 ± 11.5	72.2 ± 14.3	74.7 ± 15.0	76.6 ± 14.6	NA
Drive10	71.0 ± 7.4	82.7 ± 11.5	77.4 ± 8.8	84.3 ± 8.9	78.0 ± 6.6	84.6 ± 13.4	79.8 ± 11.2
Drive11	60.9 ± 8.7	73.8 ± 16.9	71.5 ± 17.2	76.5 ± 18.1	69.3 ± 11.1	73.1 ± 14.1	60.4 ± 10.2
Drive12	79.6 ± 4.1	87.8 ± 6.4	88.2 ± 3.5	90.5 ± 6.2	87.0 ± 4.5	88.0 ± 6.1	77.9 ± 4.9
Drive15	70.7 ± 7.1	72.1 ± 15.6	68.2 ± 11.3	72.4 ± 13.2	67.8 ± 10.7	72.7 ± 12.8	65.3 ± 14.1
Drive16	89.0 ± 9.3	107.6 ± 14.9	103.7 ± 12.1	109.3 ± 13.9	99.7 ± 12.2	101.6 ± 16.6	NA

Table 3. Segment based mean and SD values of HSC arrays.

Rec.Name	Mean HSC; Mean hand based skin conductance (uS ± SD)						
	Initial rest	City1	Hw1	City2	Hw2	City3	Final rest
Drive05	3.24 ± 1.02	8.60 ± 2.11	7.19 ± 1.02	7.25 ± 0.74	5.82 ± 0.57	6.72 ± 2.01	3.42 ± 0.91
Drive06	18.50 ± 1.46	19.60 ± 2.62	15.41 ±0.86	18.44 ± 0.83	16.93 ± 2.07	19.57 ± 0.96	18.22 ± 1.15
Drive07	4.18 ± 0.83	7.99 ± 1.42	7.04 ± 1.22	7.44 ± 1.02	6.32 ± 0.92	7.72 ± 0.79	6.75 ± 1.38
Drive08	3.27 ± 1.53	7.35 ± 0.81	5.94 ± 0.81	5.96 ± 0.87	4.98 ± 0.81	4.88 ± 0.69	3.16 ± 0.69
Drive09	2.39 ± 0.09	6.25 ± 1.91	5.82 ± 1.53	7.41 ± 0.94	5.47 ± 1.06	6.78 ± 1.43	NA
Drive10	3.24 ± 0.59	7.78 ± 2.20	6.53 ± 1.84	9.92 ± 1.97	6.34 ± 1.63	11.01 ± 2.13	10.79 ± 1.98
Drive11	2.99 ± 0.72	8.21 ± 1.92	7.25 ± 1.41	9.27 ± 1.67	7.39 ± 1.31	8.48 ± 2.01	4.07 ± 1.34
Drive12	6.46 ± 2.59	15.94 ± 1.96	16.00 ± 1.57	16.28 ± 1.67	14.92 ± 2.57	14.63 ± 1.89	8.89 ± 2.22
Drive15	4.57 ± 0.50	7.42 ± 2.24	6.10 ± 0.69	7.79 ± 1.61	7.27 ± 1.41	8.18 ± 1.45	4.41 ± 1.05
Drive16	16.04 ± 1.88	21.16 ± 2.53	20.13 ±1.15	21.39 ± 1.26	20.07 ± 0.98	21.34 ± 1.40	NA

Table 4. Segment based mean and SD values of FSC arrays.

Rec.Name	Mean FSC; Mean foot based skin conductance (uS ± SD)						
	Initial rest	City1	Hw1	City2	Hw2	City3	Final rest
Drive05	2.85 ± 0.62	6.87 ± 50	6.06 ± 0.67	6.29 ± 0.57	5.24 ± 0.56	5.46 ± 1.07	2.73 ± 0.69
Drive06	8.95 ± 1.26	12.93 ± 1.32	7.56 ± 1.26	9.70 ± 0.71	6.95 ± 1.11	7.49 ± 0.54	5.90 ± 0.46
Drive07	6.12 ± 1.54	11.56 ± 1.55	12.72 ± 1.14	13.31 ± 1.09	12.83 ± 1.16	14.31 ± 0.84	12.35 ± 0.92
Drive08	3.10 ± 0.88	7.47 ± 1.43	6.40 ± 0.72	6.56 ± 0.72	6.48 ± 1.04	6.34 ± 0.91	2.69 ± 0.94
Drive09	2.10 ± 0.13	5.05 ± 1.19	5.31 ± 1.00	6.08 ± 0.75	4.89 ± 0.94	5.27 ± 0.92	NA
Drive10	1.67 ± 0.81	9.13 ± 1.93	7.13 ± 2.20	11.07 ± 2.22	6.75 ± 2.01	9.71 ± 2.30	7.61 ± 1.60
Drive11	3.21 ± 1.00	6.76 ± 1.48	5.89 ± 0.93	6.29 ± 0.67	5.31 ± 0.64	5.48 ± 0.81	3.26 ± 0.76
Drive12	5.91 ± 2.12	8.85 ± 1.90	5.29 ± 0.51	4.33 ± 0.37	2.92 ± 0.39	1.91 ± 0.77	0.73 ± 0.02
Drive15	5.24 ± 0.68	8.29 ± 1.78	6.85 ± 0.83	7.47 ± 0.77	6.82 ± 0.76	7.18 ± 0.70	3.39 ± 1.19
Drive16	3.72 ± 0.91	7.69 ± 1.35	6.06 ± 0.66	6.33 ± 0.44	5.33 ± 0.62	6.27 ± 0.77	NA

been derived from the RESP and EMG signals, respectively. Segment based statistics related to the amplitude variations in EMG signal are given in Table 5 for each of the available drivers' bio-signal dataset.

To produce the IRR and CPM arrays, a peak detection algorithm has been used to determine the peaks of the segment based RESP and EMG signals (Billauer, 2008). MATLAB (The Mathworks, 2007) source code used for determination of the sequential peaks is given below:

```
lookmaximum = 1
for index 1 to array.length
if array(i) > max
max = array(i)
```

Table 5. Segment based statistics of the amplitude variations in EMG signal.

Rec.Name	Mean EMG; Amplitude of EMG (mV ± Sd)						
	Initial rest	City1	Hw1	City2	Hw2	City3	Final rest
Drive05	0.25 ± 0.38	2.31 ± 2.68	0.93 ± 0.85	1.89 ± 1.95	1.26 ± 1.09	1.95 ± 1.72	0.26 ± 0.65
Drive06	0.41 ± 0.40	1.62 ± 2.30	0.60 ± 0.71	2.47 ± 2.57	0.95 ± 1.34	1.52 ± 1.40	0.70 ± 0.91
Drive07	0.24 ± 0.29	0.97 ± 1.85	0.61 ± 1.92	0.99 ± 2.15	0.56 ± 1.43	1.06 ± 0.12	0.32 ± 0.78
Drive08	2.02 ± 0.74	2.60 ± 1.95	2.11 ± 0.79	2.68 ± 1.42	2.60 ± 0.99	2.34 ± 1.21	2.09 ± 1.05
Drive09	0.42 ± 0.68	1.19 ± 1.68	1.44 ± 1.63	1.28 ± 1.69	1.94 ± 0.22	1.27 ± 1.52	NA
Drive10	0.36 ± 0.24	1.09 ± 1.89	0.86 ± 1.70	2.24 ± 3.36	0.66 ± 0.84	1.30 ± 0.73	0.54 ± 0.79
Drive11	2.00 ± 0.72	2.09 ± 1.81	3.05 ± 0.81	2.24 ± 1.12	2.14 ± 0.78	2.53 ± 0.96	2.06 ± 0.71
Drive12	2.00 ± 0.85	2.09 ± 1.19	3.05 ± 3.19	2.24 ± 1.19	2.14 ± 0.80	2.53 ± 2.17	2.06 ± 0.97
Drive15	0.14 ± 0.09	1.40 ± 1.96	1.81 ± 1.60	1.45 ± 2.28	1.00 ± 1.58	1.32 ± 1.81	0.37 ± 0.47
Drive16	0.20 ± 0.05	1.32 ± 2.52	0.43 ± 0.51	1.45 ± 1.49	0.32 ± 0.48	1.67 ± 2.31	NA

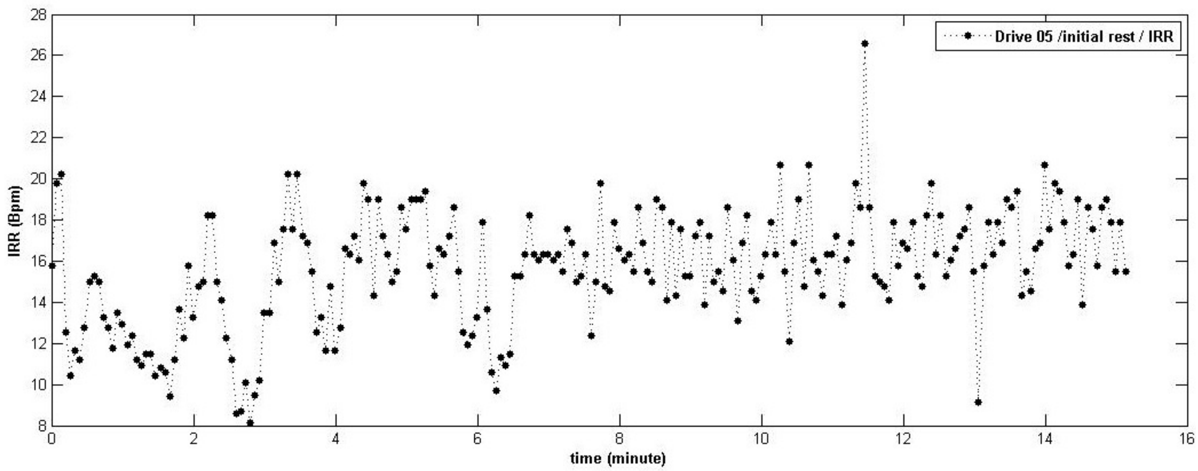

Figure 4. Plot diagram of a segment based IRR array derived from EMG signal.

```
maxpos = i
end
if array(i) < min
min = array(i)
minpos = i
end
if lookmaximum
if array(i) < max-delta
maxArray = [maxpos max]
min = array(i)
minpos = i
lookmaximum = 0
end
else
if array(i)  > min+delta
minArray = [minpos min]
max = array(i)
maxpos = i
lookmaximum = 1
end
end
end
```

Intervals between the sequential peaks of the RESP signal are measured by the time units of milliseconds and transformed to the instantaneous respiration rates, IRR, in the unit of breath per minute (Bpm), by using the following equation:

$$\mathrm{IRR} = \frac{60000}{\Delta T} \qquad (5)$$

Here IRR is determined by the unit of Bpm, ΔT is the time interval between the sequential peaks of the IRR signal in the time units of milliseconds. An example of the segment based IRR array is given with a plot diagram as in Figure 4. Both the mean and the SD of the segment based IRR arrays are given in Table 6 for each of the available drivers' bio-signal dataset.

The number of the peaks which corresponds to the number of contractions of trapezius muscle through the time interval, ΔT_s of segment based EMG signal is determined by the peak determination process given above. Depending on this peak detection process, the contraction rate which is defined as the average number of contractions in per minute time interval is calculated by using the following equation:

$$\mathrm{CPM} = \frac{NC}{\Delta Ts} \qquad (6)$$

Table 6. Segment based statistics of the IRR arrays.

Rec.Name	Mean IRR; Mean instantaneous respiratory rate (Bpm ± SD)						
	Initial rest	**City1**	**Hw1**	**City2**	**Hw2**	**City3**	**Final rest**
Drive05	15.6 ± 2.8	18.7 ± 4.5	18.4 ± 4.2	19.5 ± 4.1	19.2 ± 3.5	18.3 ± 4.2	14.3 ± 4.2
Drive06	16.6 ± 2.2	20.7 ± 3.8	20.2 ± 3.2	22.6 ± 4.3	20.9 ± 3.1	20.6 ± 4.2	16.8 ± 2.6
Drive07	13.7 ± 2.4	19.3 ± 4.3	18.2 ± 3.3	18.7 ± 3.3	16.9 ± 2.6	18.7 ± 3.7	14.1 ± 3.6
Drive08	10.9 ± 1.6	16.5 ± 4.4	18.0 ± 5.0	17.5 ± 5.0	17.3 ± 4.7	17.4 ± 4.5	12.7 ± 2.0
Drive09	14.7 ± 2.6	18.3 ± 4.2	18.9 ± 3.6	19.9 ± 4.0	17.8 ± 3.9	18.7 ± 3.8	NA
Drive10	12.7 ± 2.6	18.1 ± 5.1	19.0 ± 3.4	20.2 ± 4.8	18.4 ± 2.9	17.4 ± 5.9	12.9 ± 5.1
Drive11	16.1 ± 3.1	18.0 ± 4.4	19.5 ± 2.8	19.2 ± 4.3	19.7 ± 3.3	18.6 ± 4.0	16.3 ± 2.2
Drive12	17.9 ± 2.1	20.5 ± 5.1	21.6 ± 3.5	21.5 ± 4.9	21.4 ± 2.4	19.8 ± 5.2	18.2 ± 1.6
Drive15	12.0 ± 1.7	17.5 ± 4.1	18.0 ± 3.3	19.0 ± 3.4	18.6 ± 2.8	18.4 ± 3.8	15.9 ± 2.2
Drive16	17.8 ± 2.2	22.3 ± 4.5	22.9 ± 3.3	23.4 ± 4.6	22.3 ± 3.5	21.3 ± 5.1	NA

Table 7. Segment based total contractions and corresponding time intervals.

Rec.Name	***NC* and *ΔTs*; Total number of contractions/time interval (min)**						
	Initial rest	**City1**	**Hw1**	**City2**	**Hw2**	**City3**	**Final rest**
Drive05	1680/15.13	4194/16.00	1700/7.74	1534/6.06	1876/7.56	3927/14.96	1352/15.78
Drive06	2257/15.05	3427/14.49	1284/7.32	1742/6.53	1446/7.64	2972/12.29	3200/15.05
Drive07	1492/15.04	3257/16.23	2040/10.96	2244/9.83	1454/7.64	2191/10.15	1794/15.03
Drive08	2693/15.00	2156/12.31	1304/7.23	1565/9.51	1293/7.64	2438/13.43	2647/15.07
Drive09	967/15.66	3433/19.21	1619/8.47	983/5.20	1821/7.06	2345/13.21	NA
Drive10	1218/15.04	2371/15.30	1326/8.66	1316/5.27	1020/7.04	2345/12.06	1759/14.79
Drive11	3573/15.02	3689/15.81	1635/7.43	1625/7.15	1519/6.96	2610/11.72	3589/14.99
Drive12	3010/15.01	2239/13.41	1247/7.56	1092/6.50	1463/8.06	2001/11.68	3002/15.01
Drive15	968/15.00	2506/12.54	1758/7.24	1236/5.99	1087/6.82	2240/12.12	1763/15.00
Drive16	1565/15.01	3946/16.12	1906/7.14	1416/5.12	1024/6.81	2905/13.91	NA

Table 8. Segment based contraction rates in the unit of cpm.

Rec.Name	CPM; Number of contractions per minute (cpm)						
	Initial rest	**City1**	**Hw1**	**City2**	**Hw2**	**City3**	**Final rest**
Drive05	111	262	220	253	248	263	86
Drive06	150	236	175	267	189	242	213
Drive07	99	201	186	228	190	216	119
Drive08	180	175	180	165	169	182	176
Drive09	62	179	191	189	258	177	NA
Drive10	81	155	153	250	145	194	119
Drive11	238	233	220	227	218	223	239
Drive12	200	167	165	168	181	171	200
Drive15	65	200	243	206	159	185	118
Drive16	104	245	267	276	150	209	NA

Here CPM is the contraction rate given with the unit of contractions/minute, cpm. ΔT_s time interval of the EMG segment is given by the unit of minutes. The segment based total number of contractions (*NC*) along the related segments is given in Table 7 with the time intervals of related segments for each of the available drivers' bio-signal dataset. Resulting segment based contraction rates given by the unit of cpm is given in Table 8 for each of the available drivers' bio-signal dataset. In order to make evaluations

Table 9. Statistics of IHR and HSC arrays related to rearranged R, H, C segments.

Rec.Name	Mean IHR (bpm ± SD)			Mean HSC (μS ± SD)		
	R	H	C	R	H	C
Drive05	65.4 ± 7.2	72.9 ± 6.8	77.8 ± 9.0	3.33 ± 0.97	6.51 ± 1.08	7.62 ± 2.10
Drive06	80.2 ± 9.3	88.3 ± 10.3	99.5 ± 12.3	18.36 ± 1.32	16.19 ± 1.77	19.36 ± 1.91
Drive07	70.8 ± 8.4	73.4 ± 5.5	78.3 ± 7.6	5.46 ± 1.72	6.75 ± 1.16	7.77 ± 1.19
Drive08	63.4 ± 0.2	66.5 ± 11.0	73.1 ± 16.5	3.21 ± 0.67	5.45 ± 0.97	6.03 ± 1.54
Drive09	66.2 ± 8.6	72.8 ± 13.3	73.7 ± 12.3	2.39 ± 0.09	5.66 ± 1.35	6.59 ± 1.69
Drive10	75.4 ± 10.5	77.7 ± 7.9	83.7 ± 11.9	6.98 ± 4.05	6.44 ± 1.75	9.32 ± 2.61
Drive11	60.7 ± 9.4	70.4 ± 14.6	74.1 ± 16.3	3.53 ± 1.21	7.32 ± 1.36	8.52 ± 1.94
Drive12	78.7 ± 4.6	87.6 ± 4.1	88.4 ± 6.3	7.67 ± 2.70	15.44 ± 2.21	15.53 ± 2.00
Drive15	68.0 ± 15.9	68.0 ± 11.0	72.4 ± 14.1	4.49 ± 0.82	6.67 ± 1.25	7.79 ± 1.87
Drive16	89.0 ± 9.3	101.7 ± 12.3	108.0 ± 14.7	16.04 ± 1.88	20.10 ± 1.07	21.22 ± 2.30
Overall	71.8 ± 9.7	77.9 ± 11.9	82.9 ± 12.6	7.15 ± 1.88	9.65 ± 1.45	10.98 ± 1.95

Table 10. Statistics of FSC and EMG arrays related to rearranged R, H, and C segments.

Rec.Name	Mean FSC (μS ± SD)			Mean EMG (mV ± SD)		
	R	H	C	R	H	C
Drive05	2.78 ± 0.66	5.66 ± 0.74	6.21 ± 1.38	0.26 ± 0.54	1.09 ± 0.99	2.10 ± 2.23
Drive06	7.42 ± 1.80	7.25 ± 1.22	10.29 ± 2.64	0.56 ± 0.72	0.78 ± 1.09	1.75 ± 2.11
Drive07	9.23 ± 3.36	12.77 ± 1.15	12.81 ± 1.73	0.28 ± 0.59	0.59 ± 1.73	1.00 ± 2.01
Drive08	2.89 ± 0.93	6.44 ± 0.90	6.80 ± 1.19	2.06 ± 0.91	2.36 ± 0.93	2.52 ± 1.57
Drive09	2.10 ± 0.13	5.12 ± 0.99	5.27 ± 1.10	0.42 ± 0.68	1.67 ± 1.48	1.23 ± 1.63
Drive10	4.62 ± 3.23	6.96 ± 2.12	9.66 ± 2.23	0.45 ± 0.59	0.77 ± 1.38	1.35 ± 2.18
Drive11	3.24 ± 0.89	5.61 ± 0.86	6.23 ± 1.28	2.12 ± 0.72	2.12 ± 0.80	2.38 ± 1.45
Drive12	3.32 ± 2.99	4.07 ± 1.27	5.35 ± 3.40	2.03 ± 0.91	2.58 ± 2.33	2.28 ± 1.64
Drive15	4.31 ± 1.34	6.84 ± 0.80	7.69 ± 1.37	0.25 ± 0.36	1.42 ± 1.64	1.38 ± 1.97
Drive16	3.72 ± 0.91	5.70 ± 0.74	7.36 ± 1.33	0.20 ± 0.05	0.38 ± 0.50	1.36 ± 2.31
Overall	4.36 ± 1.97	6.64 ± 1.15	7.77 ± 1.91	0.86 ± 0.65	1.37 ± 1.38	1.74 ± 1.93

for 3 types of driver stress corresponding to 3 types of driving conditions, all the segment based statistical parameters related to the IHR, FSC, HSC, EMG, IRR and CPM arrays have been recalculated for the complete rest, city driving and highway driving periods of each driving.

For this aim, the data arrays related to the 2 segments of the rest period have been added together to form the data arrays related to the complete rest (R) segment of each drive corresponding to the low level stress conditions. Similarly, the data arrays related to the 2 segments of highway driving periods have been added together to form the data arrays related to the complete highway (H) segment of each drive corresponding to the medium level stress conditions, and the data arrays related the 3 segments of the city driving periods have been added together to form the data arrays related to the complete city (C) segment of each drive corresponding to the high level stress conditions. Segment based statistics for the IHR, HSC, FSC, EMG, IRR and CPM arrays related to rearranged R, H and C periods of 10 drivers' bio-signal datasets have been calculated. The results are given in Tables 9, 10, and 11 with the overall mean and SD values. Obtained results and overall statistics of the IHR and HSC arrays related to rearranged R, H, and C segments are given in Table 9.

Obtained results and overall statistics of the FSC and EMG arrays related to rearranged R, H, and C segments are given in Table 10. Obtained results and overall statistics related to IRR and CPM arrays of rearranged R, H, and C segments are given in Table 11. Resulting overall statistics given in the bottom row of the Table 9, 10 and 11 include the overall mean and SD values of the IHR, HSC, FSC, EMG, IRR and CPM arrays related to the rearranged R, H, C segments of the drives. Here overall means have been calculated as the average of the means of the related segment based data:

$$\mu_s = \frac{1}{10}\sum_{n=1}^{10} \mu_{n_s} \quad (7)$$

Here, n represents the drive number index, μ_{ns} is the mean and μ_s is the overall mean of the rearranged segment based data. Similarly, overall SD values have been calculated as the square root of the average variance of the rearranged segment based variances:

$$\sigma_s = \sqrt{\frac{1}{10}\sum_{n=1}^{10} (\sigma_{n_s})^2} \quad (8)$$

Table 11. Statistics of IRR and CPM arrays related to rearranged R, H, and C segments.

Rec.Name	Mean IRR (Bpm ± SD)			Mean CPM (cpm)		
	R	H	C	R	H	C
Drive05	15.0 ± 3.6	18.8 ± 3.9	18.7 ± 4.3	98	234	259
Drive06	16.7 ± 2.4	20.6 ± 3.2	21.1 ± 4.1	181	182	248
Drive07	13.9 ± 3.1	17.7 ± 3.1	19.0 ± 3.9	109	188	215
Drive08	11.9 ± 2.0	17.7 ± 4.8	17.1 ± 4.6	178	175	174
Drive09	14.7 ± 2.6	18.4 ± 3.8	18.7 ± 4.0	62	224	182
Drive10	12.8 ± 3.8	18.8 ± 3.2	18.3 ± 5.4	100	149	200
Drive11	16.2 ± 2.7	19.6 ± 3.0	18.5 ± 4.3	239	219	228
Drive12	18.1 ± 1.9	21.5 ± 3.0	20.5 ± 5.1	200	173	169
Drive15	14.2 ± 2.8	18.3 ± 3.0	18.1 ± 3.9	91	201	197
Drive16	17.8 ± 2.2	22.6 ± 3.4	22.6 ± 4.5	104	209	243
Overall	15.1 ± 2.8	19.4 ± 3.5	19.3 ± 4.4	136	195	211

Here, n represents the index of drive number, σ_{ns} is the SD and σ_s is the overall SD of the rearranged segment based data. The overall statistics related to the rearranged R, H and C driving segment based data have been evaluated as the representing metrics of the corresponding low, medium and high level of stress. Final evaluations based on these statistical data are given in the following paragraphs.

RESULTS

Statistical data given in Tables 2, 3 and 4 supports that the means of the segment based IHR, HSC and FSC arrays are correlated with 3 different stress levels of drivers for most drivers studied. So that, increasing stress levels cause the increasing instantaneous heart rates and increasing hand/foot based skin conductance, simultaneously. So that, referring to the overall means given in Tables 9 and 10, segment based means related to rearranged R segments are 71.8 bpm for IHR, 7.15 micro-Siemens for HSC, 4.36 micro-Siemens for FSC, respectively. The same data are 77.9 bpm for IHR, 9.65 micro-Siemens for HSC, 6.64 micro-Siemens for FSC, referring to rearranged H segment based overall means. They are 82.9 bpm for IHR, 10.98 micro-Siemens for HSC, 7.77 micro-Siemens for FSC, referring to rearranged C segment based overall means.

Therefore, overall means of the H segment based data have 8.5% increasing values for IHR, 35% increasing values for HSC, 52.3% increasing values for FSC, referring to the overall means of R segment based results. Similarly, overall means of the C segment based data have 15.5% increasing values for IHR, 53.6% increasing values for HSC, 78.2% increasing values for FSC, referring to the overall means of R segment based results. In addition, referring to the IHR data, overall SD values have 13.6, 15.2 and 15.1% of corresponding means of the R, H and C segment based data, respectively. Similarly, referring to the HSC data, overall SD values have 26.3% 15, and 17.8% of corresponding means and referring to the HSC data, overall SD values have 45.2, 17.3, and 24.6% of corresponding means related to the R, H and C segment based data, respectively. Thus SD values of the data are not correlated with the corresponding stress levels. However, due to these results, it can be stated that, variance of the IHR, HSC and FSC data can have a limited disturbances on measuring process for these metrics. Therefore, it can be stated that, the IHR and skin conductance (HSC and/or FSC) metrics representing the average of the measurements through a few minutes length of time interval can be used to decide the dynamic stress level of drivers. This also supports the results obtained by the Healey and Picard's (2005) study.

Like IHR and SC arrays, the statistical data given in Table 5 supports that the 3 different stress levels of drivers are correlated with the means of the amplitudes of the segment based EMG arrays and their SD values for most drivers studied. However, SD values related to this segment based data can vary at a range of their mean values. Increasing stress level causes the increasing mean and increasing SD of the amplitudes of EMG recording in related segments. So that, referring to the overall means given in Table 10, segment based means of the EMG amplitudes are 0.86, 1.37, and 1.74 mV, respectively for rearranged R, H and C segments. Therefore, referring to the overall means of R segment based data, overall means of the H segment based data have 59.3% increasing value and C segment based data have 102.3% increasing value. In addition, overall SD values have 112.3% increasing value and 197% increasing value for H and C segments, referring to the overall means of related segment based data. Therefore, it can be stated that, the average of the EMG amplitude measurements and their SD values through a few minutes length of time interval can be used as related metrics to decide the dynamic stress level of drivers.

Statistical data given in Table 6 shows that the means of the segment based IRR arrays reflect the rest and driving conditions of the drivers. So that, referring to the overall means given in Table 11, segment based means of the IRR values are 15.1, 19.4, and 19.3 Bpm, respectively for rearranged R, H and C segments. Therefore, referring to the overall means of R segment based data overall means of the H segment based IRR have 28.5% increasing value and C segment based IRR have 27.8% increasing value. In addition, overall SD values have 25.2% increasing value and 59.7% increasing value for H and C segments, referring to the overall means of related segment based data. Therefore, it can be stated that, in all cases the IRR metric representing the average of the measurements through a few minutes length of time interval can be used to indicate the rest or driving conditions of the drivers.

Finally, statistical data given in Tables 7 and 8 show that the segment based CPM arrays reflect the 3 stress levels of drivers. Increasing stress level causes the increasing contraction rates of trapezius muscle in related segments. So that, referring to the overall means given in Table 11, segment based means of the CPM are 136, 195, and 211 cpm, respectively for rearranged R, H and C segments. Referring to the overall means of R segment based data overall means of the H segment based data have 43.4% increasing value and C segment based data have 55.2% increasing value. Therefore, it can be stated that, the CPM metric representing the average of measurements in a few minutes length of time interval can be used to decide the dynamic stress level of the drivers.

Conclusions

Totally 10 of drivers' bio-signal datasets obtained from MIT-BIH Multi-parameter Database (PhysioNet, 2010) were used to quantify the stress level of drivers in this study. Evaluations have been completed by using the available segment based arrays of IHR, HSC, FSC and EMG signals. For further evaluations, the segment based data arrays including IRR and CPM have been derived from the RESP and EMG signals, respectively. Statistical comparisons using the mean and overall mean values of the IHR, HSC, FSC, EMG, IRR and CPM data arrays showed that with an optional exception of IRR arrays all of these metrics can be identified as useful parameters in the future car technology to determine the dynamic stress level of the drivers. However, this exception must be confirmed by the future studies.

Because of that peak detection algorithms might be required new respiratory signal recordings other than available respiratory signal, such as recordings by the abdomen based measurements. However, in all cases, beside the segment based mean values of the IHR, HSC, FSC, EMG, ICPM and segment based SD values of the amplitude of EMG signal, segment based IRR arrays can be used at least to indicate the internal states related to the rest and driving conditions of drivers. As a conclusion, it can be stated that mean of the IHR, HSC, FSC, EMG and CPM metrics related to the measurements through a few minutes length of time interval can be used to indicate dynamic stress level of drivers. In addition, SD values related to EMG amplitude measurements can be used for this aim. However, in all cases, IRR metric can be used to indicate the rest versus driving conditions of the drivers.

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