DrivingStyles: Assessing the Correlation of Driving Behavior with Heart Rate Changes

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Abstract. Driving safety is of utmost importance in our society. The number of fatalities due to car accidents is still very high, and reducing this trend requires as much attention as possible. There are situations where the emotional conditions of drivers vary due to either reasons beyond their control, or because they decide to change their driving style. Hence, we consider that such frequent situations deserve more scrutiny. In this paper we designed an Android application able to monitor in real-time both physiological data from the driver and diagnostic data from the vehicle to study their correlation. More specifically, we study the connection between driving aggressiveness and heart rate. The vehicle diagnostic data is obtained using an OBD-II connector. Among the various non-invasive biomedical sensors available nowadays, in this work we focus on heart rate sensors, either packaged in belts or in smart watches.

Keywords: Driving styles · Android smartphone · OBD-II · Neural networks · Driving behavior · Heart rate · Heart rate belt · Eco-driving · Consumption · Road safety

1 Introduction

It is known that prolonged or repeated stress, such as long traffic jams or driving on severely congested roads, is related to increased aggressiveness. In fact, authors like Gibson and Wiesenthal [1], Cohen [2], and Gravina et al. [3,4] have identified a potentially dangerous aggressiveness level as a result of driver stress. Thus, any method or system that can help at lowering the levels of aggressiveness when driving is welcome.

Our proposal just needs basic devices, such as a mobile phone, and an On Board Diagnostics (OBD-II) device [5–7], available for less than 20 dollars, along with a heart rate band or a smart watch. Our novel DrivingStyles architecture adopts data mining techniques and neural networks to analyze and generate a classification of the driving styles based on an analysis of the characteristics of the driver along the route followed. It ensures that the driver can be constantly aware of its level of aggressiveness and driving stress, and how this affects to his heart rate. In a previous study [8], we developed a methodology to calculate, in

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real-time, the impact that the driving style will have on the consumption and environmental impact of spark ignition and diesel vehicles. We demonstrated that an aggressive driving style increases the fuel consumption, as well as the emission of greenhouse gases.

In this paper we go one step forward and demonstrate that a more aggressive driving behavior also leads to a heart rate increase of at least three beats per minute with respect to a quiet behavior. The analysis has been carried out with 460 min of driving, taking 27663 direct samples (obtained from the vehicle's ECU and the driver's heart rate band), which corresponds to 5532 time windows where the driver behavior and road types are analyzed. Our platform is able to assist drivers in correcting their bad driving habits, while offering helpful recommendations to improve fuel economy, and driving safety.

This paper is organized as follows: in the next section we present the DrivingStyles architecture. The method used for the analysis of the variables is presented in Sect. 3. We present experimental results in Sect. 4. Finally, in Sect. 5, we review the main conclusions and discuss future work.

2 General Overview of the DrivingStyles Architecture

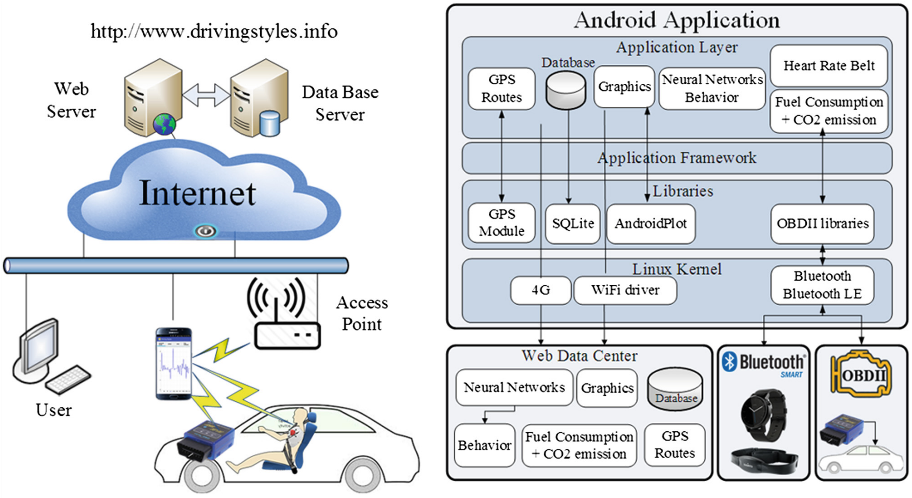
Our proposed architecture applies data mining techniques to generate a classification of the driving styles of users based on the analysis of their mobility traces using neural networks. Such classification is generated taking into consideration the characteristics of each route, such as whether it is urban, suburban, or highway. To achieve the overall objective, the system is structured around the following two elements:

1. An application for Android-based smartphones which is responsible for collecting data from the car and the driver's heart rate band or smart watch, which also analyzes routes and driver behavior using neural networks.
2. A cloud-based data center to collect large data sets sent by different users concurrently. Subsequently, these data are analyzed using data mining and expert systems, in order to generate useful information.

2.1 Android Application

Using an OBD-II Bluetooth interface, the Android application (see Fig. 1b) collects information such as speed, acceleration, engine revolutions per minute, throttle position, and the vehicle's geographic position. It also obtains information from a wearable heart rate monitor, chest belts and smart watches. This information is analyzed on the device itself, performing the analysis of driver behavior and road type (using neural networks), instantaneous fuel consumption, greenhouse gas emissions, and heart rate measurement.

We then provide feedback from the device to the user in a way that, when the application detects high levels of aggressiveness, (above a certain threshold), the device generates an acoustic signal to alert the driver. Furthermore, if the



(a) Overview of the architecture

(b) Block diagram of the architecture

Fig. 1. System architecture of DrivingStyles: overview and block diagram architecture.

user has a wearable device, such as a smart watch, it is notified by a vibration event as well.

Eventually, the user uploads the route data to the remote data center for a more comprehensive analysis. The Android application is a key element of our system, proving connectivity to the vehicle and to the DrivingStyles web platform. The application, which is available as a free download in the DrivingStyle's website and from Google Play Store[1], has achieved nearly 6000 downloads from different countries in just one year. This indicates the great interest of this type of user-level applications. For more detailed information please refer to [8,9].

2.2 Data Center

Our data center[2] is able to collect large data sets sent by different users (see Fig. 1a). There are currently 485 registered users and 411 routes sent for study. The data center allows users and administrators to access data about routes and per-user statistics. In particular, users can access all the routes they have uploaded.

3 Research Strategy and Methodology

We now present the methodology we have followed in order to correlate driving aggressiveness and driver heart rate by using the data provided by our DrivingStyles architecture.

1 https://play.google.com/store/apps/details?id=com.driving.styles.
2 http://www.drivingstyles.info.

3.1 Participant

The data reported in the present study were collected from a 35 years old male driver, without heart diseases, and whose heart rate while at rest lies between 70 bpm (beats per minute) and 75 bpm. We have analyzed twenty-one routes of varying durations, and under completely different environments (urban, suburban or highway), and also at different weather conditions (rainy, sunny, cloudy, etc.) and road conditions. This diversity allowed us to analyze the system reliability under different environmental conditions [10].

The driver was equipped with an Android device with our DrivingStyles application, and a heart rate band (brand Geonaute, although any other compatible band could be used as well) attached to the driver's chest.

3.2 OBD-II Instrument

The vehicle used for testing is a gasoline model of the KIA brand with manual transmission. It was instrumented with an interface compatible with the On Board Diagnostics (OBD-II) standard [5,6], available since 1994 [7], and that has recently become an enabling technology for in-vehicle applications due to the appearance of Bluetooth OBD-II connectors [7,11]. These connectors enable a transparent connectivity between the mobile device and the vehicle's Electronic Control Unit (ECU).

3.3 Heart Rate Monitor (HRM)

Regarding heart rate monitor (HRM) devices, there are mainly two types on the market: the smart-watch (or other wrist band) and the chest strap. Smart-watch models tend to be less accurate than chest-strap HRMs. Tests were conducted with different models of both types. The first devices used were wrist devices, including the Motorola 360 smartwatch. In this model the back of the watch hosts the heart rate sensor. Despite using oximeter technology pulse measurement, in our tests, the sampling frequency of the smart watch was too low and, in combination with the high battery consumption when the heart rate measurement is activated, made us disregard this device from the beginning. So, we opted for the heart rate belt device instead.

Heart rate belt operation is simple, an electrical signal is transmitted through the heart muscle in order for it to contract. This electrical activity can be detected through the skin. The transmitter part of the heart rate monitor is placed on the skin around the area that the heart is beating, and picks up this signal. The transmitter then sends an electromagnetic signal containing heart rate data to the wrist receiver which displays the heart rate.

As we can see in Fig. 2, the Android app displays the heart rate in real-time, as well as a map representation of the heart rate compared with the average of the route undertaken so far, being red if it is higher than average, and green otherwise. It is mandatory that the mobile device used supports Bluetooth Low Energy (Bluetooth LE, BLE) to connect with the heart rate monitor.

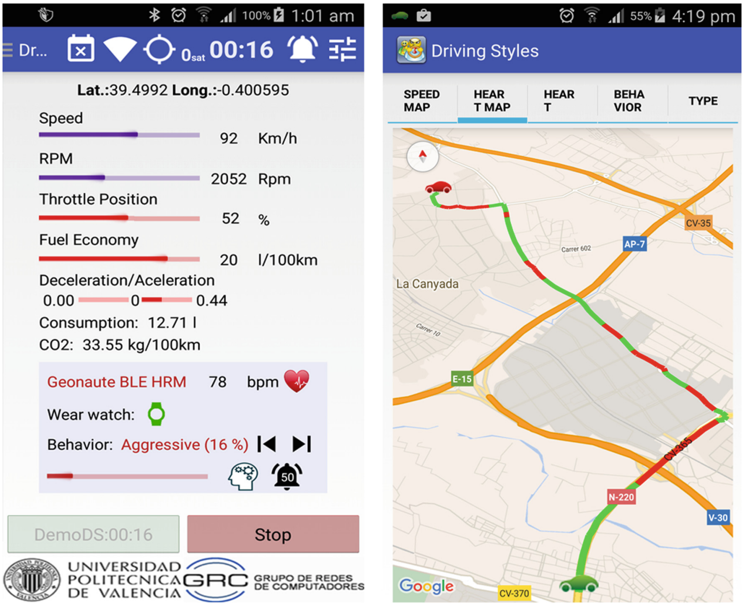


Fig. 2. Snapshots of the main screen and the heart rate module. (Color figure online)

Table 1. Mean, standard deviation, and range of route time, speed, and heart rate.

	Mean	SD	Range
Route time (*minutes*)	24.63	26.37	6.32–81.44
Speed (*km/h*)	67.44	41.30	0–135
Heart rate (*bpm*)	79.73	10.87	55–115

3.4 Measurement Result

The total time of the twenty-one routes considered for this study has been 7 h and 40 min (460 min). Regarding the heart rate, 27663 direct samples (one sample every second) have been obtained. Also 5520 driving behavior measures calculated by the neural network have been used in the test, reflecting the behavior of the driver at measurement time (behavior analysis is performed with data from 5 s before performing the calculation). See Table 1 for further information.

Before performing the statistical calculations, the samples were normalized between 0 and 1. The neural network developed returns a value between 0 and 100, as a result of analizing each type of behavior. These values must also be normalized before the statistical study.

In Sect. 4 we proceed to analyze the correlation between driving behavior and the driver's heart rate.

4 Experimental Results and Evaluation

We can assume that drivers can be exposed to higher levels of stress during rush-hours in a city [12]. Similarly, the sparsest traffic conditions can be found on country side roads, driving on highways or in sparsely populated areas. Hence, these two conditions should represent the far ends that we should find in the routes under analysis.

Our study is based on a set of twenty-one different routes made by the same driver on a same vehicle in an attempt to eliminate these factors, and focuses solely on the relation between driving aggressiveness and heart rate. Then, we focus on a particular route to have a more in-depth perspective of the results obtained and the overall findings. In both cases, we obtain through linear regression the line that better describes the correlation between both data sets. This way, a positive gradient shall validate our assumption of a positive correlation between driver behavior and heart rate, as intended.

4.1 On-road Tests (All Routes)

First, we analyzed the twenty-one routes mentioned previously in Sect. 3.4. The total time of all these routes is 460 min of driving, which corresponds to a total of 27663 direct samples and 5532 behavior samples calculated by the system. Notice that the developed neural network evaluated the three types of driver behavior at once, generating an output score for each that allows generating an output in the range from 0 to 1.

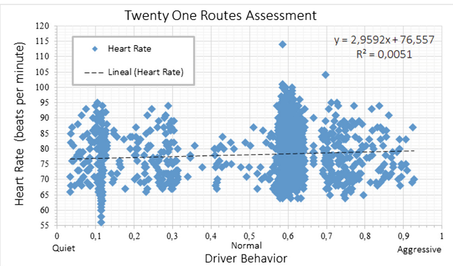


Fig. 3. Correlation between heart rate and driving behavior.

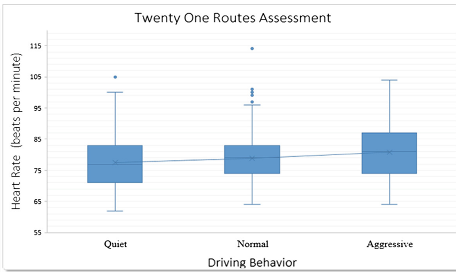


Fig. 4. Box and wisker plot of heart rate vs driving behavior.

Figures 3 and 4 show the correlation plots between heart rate and behavior of the 27663 samples obtained for the study. Table 2 shows the equation of the corresponding slope-intercept form, where the slope given by m, which equals to 2.959, and the y-intercept by b, which is equal to 76.557 (see Fig. 3). As it can be observed, the intended correlation between driving styles and heart rate R is 0.071. The correlation value obtained is not as significant when compared to result for a particular route, as shown in the following section.

Table 2. Slope-intercept form equation of single route and all routes.

	y	m	R^2	R
Behavior single route				
Quiet-normal	$8.692x + 72.72$	8.692	0.172	0.414
Normal-aggressive	$5.667x + 74.049$	5.667	0.041	0.203
Quiet-normal-aggressive	$6.937x + 73.362$	6.937	0.173	0.416
Behavior all routes				
Quiet-normal-aggressive	$2.959x + 76.557$	2.959	0.005	0.071

These results were mostly expected since the driver remains seated in all cases, and so the additional physical burden requiring a higher heart beat is not comparable to more demanding situations. It is noteworthy mentioning, though, that in this section we are studying routes of many types, some from urban scenarios and other from highway scenarios, being the behavior less aggressive for the latter. So, overall, we find that the difference between a quiet behavior and an aggressive behavior for a specific driver is a heart rate increase of 3.72%. Figure 4 shows the box and wisker plot of heart rate vs driving behavior. We find that the difference in heart rate between quiet and aggressive behavior is 3.25% (about three beats per minute).

4.2 On-road Tests (Single Route)

In this second part of the analysis, we study a specific route chosen from the set of twenty-one routes analyzed in this paper. The DrivingStyles platform, in addition to analyzing the behavior, is also able to compute the route type.

In particular, this route has a duration of 6 min and 33 s, circulating at an average speed of 24 km/h and a maximum speed of 57 km/h, covering a total of 2.17 km; this corresponds to 381 behavior type samples, also including data about the driver's heart rate that we use in the statistical analysis.

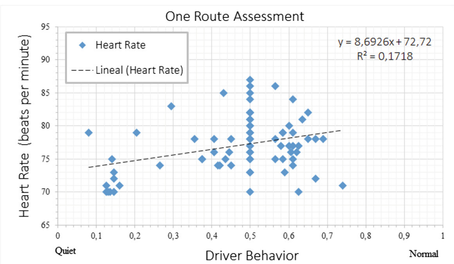


Fig. 5. Correlation between heart rate and driving behavior (quiet-normal).

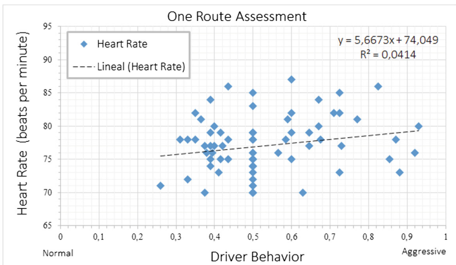


Fig. 6. Correlation between heart rate and driving behavior (normal-aggressive).

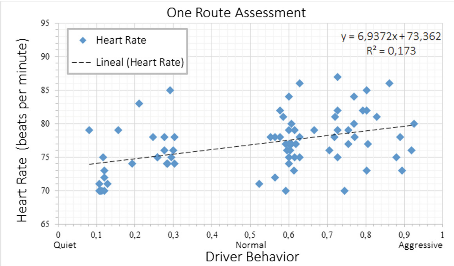


Fig. 7. Correlation between heart rate and driving behavior.

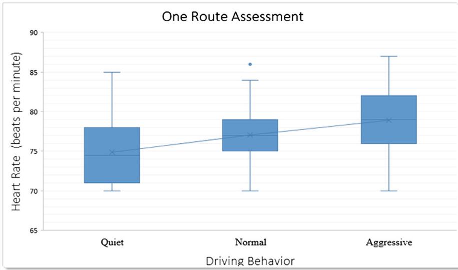


Fig. 8. Box and wisker plot of heart rate vs driving behavior.

After normalizing the data as explained in Sect. 3.4, we split our analysis into three parts: the difference in terms of heart rate between quiet and normal behavior (see Fig. 5), the same difference between normal and aggressive behavior (see Fig. 6), and a full comparison between quiet, normal, and aggressive driving (see Figs. 7 and 8):

1. Concerning the first case study i.e., when comparing the heart rate between a quiet behavior and normal behavior (see Fig. 5), we find that the linear trendline has a positive slope (8.69) and the *R-squared* value or coefficient of determination is 0.17 (how close the data are to the fitted regression line). As shown in this figure, there is a clear correlation between heart rate and driver behavior, being the heart rate when the system detects normal behavior about 10.67% higher compared to a quiet behavior.
2. In Fig. 6 we compare the normal driver behavior against an aggressive behavior for the same route. We find that the slope of the regression line is lower than for the plot previously discussed (quiet behavior vs normal behavior), having a value of 5.66, being the coefficient of determination significantly lower, with a value of 0.04. Observing both plots (see Figs. 5 and 6), we find that, regarding the outputs of the neural network implemented, the computation of the driver's behavior tends to provide as outcome that is either a quiet behavior or an aggressive behavior in most cases, being intermediate values more scarce. In this case, the heart rate difference is 7.20% higher between aggressive behavior and the normal behavior.
3. In the third scenario, all the system's outputs were jointly analyzed (see Figs. 7 and 8). We find that the linear trendline remains positive, being the slope value of 6.93, and the coefficient of determination is 0.17. In this last analyzed case the difference between a quiet behavior and an aggressive behavior is 8.61%. The results obtained are very similar to the first plot (see Fig. 5), which leads us to consider whether it would be interesting, in future studies, to train the neural network to have only two outputs instead: quiet behavior and aggressive behavior.

Finally, the box and whisker plot (see Fig. 8) displays the differences between quiet, normal, and aggressive driving behavior vs heart rate; for this test subject, an aggressive driving provoked an increased heart rate. If we look at the value of the median in the three types of behavior (quiet, normal and aggressive) we see that the difference in heart rate between a quiet and normal behavior is 2.78% (about two beats per minute); similarly, between a normal and an aggressive behavior, this difference is 2.41% (about two beats per minute as well). Summarizing, according to our findings, the driver's pulse increased by 5.18% (slightly more four beats per minute) when the driver switched to a more aggressive driving compared to a quite driving style.

5 Conclusions and Future Work

In this paper we studied the correlation of the driver heart rate with respect to his driver behavior. We based our study on the use of our novel DrivingStyles architecture, that combines new technologies such as smartphones and wearable body sensors with the modern software implementations of artificial neural networks.

The results of the present study indicated that aggressive driving causes an increase in the heart rate, being able to rise it by up to three beats per minute on average. Based on our experimental results, we have reached the conclusion that the difference in terms of heart rate between a quiet and aggressive behavior can become very noticeable. In statistical terms, we also found that, as the number of samples increases, the correlation between the driver behavior and heart rate becomes lower. This was expected since increasing the number of routes whose behavior is largely quiet, makes the percentage of values with an aggressive behavior to decreases, i.e., an urban route that causes stress and aggressiveness will get closer to our results that a long highway route where the stress is non-existent or scarce. Since this study has been conducted taking a middle-aged male subject as reference, in future works we will expand the scope of our study to women, and also to drivers of different ages, which will help at covering a wider range of possible cases. This will allow us to study the differences between various age segments, as well as to differentiate driving aggressiveness and heart rate based on the driver's gender.

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