The Effect of Individual Stress Zones on Car-Racing Performance

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***Abstract*— Car racing on track is a physically and mentally demanding sport. The car is monitored with high accuracy to improve performance, but nothing is measured on the driver. To achieve high performance, it is important that the driver is at their peak both physically and mentally. Knowing the mental state of the driver and keeping them in their individual focus zone can help improve the performance of the team. The stress level of four drivers is monitored during a 10hr race. Individual Stress Zones are calculated and used to distinguish mental states of distraction, focus and distress. The results show that performance is 1.7% better when focused than when distracted (for 1 of 4 drivers) and 2.3% better than distressed (for 3 of 4 drivers).**

I. Introduction

Car-racing on track is a complex and demanding sport, both for the drivers and car. For a team to be successful, they must have a competitive car. Therefore, considerable money and effort are spent to make this happen. Each part of the car is monitored with high accuracy, and set up to perfection. The driver on the other hand is rarely monitored.

Racing requires drivers to be skilled, and physically and mentally in good shape. Each driver error not only affects performance (e.g. losing the race), but can also have an impact on safety (e.g. crashing the car) and economics (e.g. financial losses for the team). Therefore, it is beneficial to monitor the (mental) status of the driver.

In sports applications (and in daily life), it is known that a certain stress level is required to perform well [1]. If the stress level is too high, the athlete is in distress. If the stress is too low, the athlete might be too calm and not focused on the task. In both cases, the performance will not be optimal. Knowing the actual mental state of the driver and keeping them in their individual focus zone, can help improve the performance of the team in terms of both results and safety.

Kamata et al. [2] proposed a probabilistic model to estimate the Individual Zone of Optimal Functioning (IZOF). It aims to predict the quality of upcoming performance with respect to the current or anticipated pre-performance emotional state of the performer. Edmonds et al. [3, 4] tested this approach in a simulated car-racing task. They found that the IZOFs are individually different for each participant, in terms of probability and range. Due to the complex conditions, limited research has been conducted on mental state monitoring during actual car-racing on track. Schwaberger [5] and Tsopanakis et al. [6] have looked at stress hormones, while Matsumura et al. [7] focused on karting. Simulator studies [8, 9, 3, 4] do not consider the high physical load on the drivers, and are therefore also limited in scope. Thus, no system is available to monitor the mental state of race drivers during a race, and much less provide information for improving performance of the driver.

In this study, a system is used to monitor the stress level of drivers during car-racing on track. This is a follow-up of earlier research that focused on football [10] and horses [11, 12]. The probabilistic model of Kamata et al. [2] is used to identify Individual Stress Zones (ISZ) for each driver. Sector performance is finally compared between ISZ.

II. Materials and Methods

A. Experimental Setup

Four male drivers participated in this study. They drove in a BMW M235i during a 10hr race on the circuit of Zolder [13]. In this race, each team consists of at least 2 drivers that are taking turns in driving the car. The circuit of Zolder consists of three sectors, which are respectively 1.35km, 1.45km and 1.18km long. In total 307 laps were driven by the team in 8 stints (2 stints per driver).

B. System description

The stress level monitoring system consists of four Mio ALPHA (Mio Global, Canada) heart-rate sensors, and the Sony M4 Aqua (Sony Corporation, Japan) smartphone.

Figure 1. Schematic overview of the stress level monitoring system in a race car

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The smartphone is attached to the roll-cage of the car. The heart-rate of each driver is measured via optical sensors on the wrist by a Mio ALPHA at 1Hz, and is sent to the smartphone via Bluetooth when it is in its proximity. A schematic overview of the system is given in Figure 1.

A custom-made Android application combines the heart-rate of each driver with the internal 3D accelerometer (50Hz, range ± 2G) to calculate the stress level. The principle of stress level monitoring is the same as the one presented by Jansen et al. [12].

For each sector, the average stress level of the driver is calculated for further analysis. If there is no data because of faulty Bluetooth connection, the sector is discarded.

C. Performance

The time needed for a driver to finish a sector, is defined as sector time. Sector times are converted to a performance score using the formula of (1).

$$\text{performance} = 100 * (1 - \frac{\text{Sector time}}{\text{Best sector time}}) \qquad (1)$$

The performance score is assessed individually and relative to the personal best sector time of the driver during the race. Negative performance values indicate that sectors were driven slower than the drivers' personal best. Performance scores are discarded when the car enters or leaves the pit-box.

A threshold is defined for each driver as the 30% quantile from all the performance scores of this driver. Each performance score is then evaluated as optimal (faster than the threshold), or moderate (slower than the threshold). An example is shown in Figure 2.

Following the approach presented in [2], moderate performance is further differentiated by low stress and high stress. First, the median stress level ($\hat{\mu}_{OP}$) of sectors corresponding to optimal performance is computed. Second, moderate performance associated with stress that is lower than $\hat{\mu}_{OP}$ is considered to be moderate performance with stress level below the optimal stress. Moderate performance associated with stress higher than $\hat{\mu}_{OP}$ is considered as moderate performance with stress level above the optimal stress.

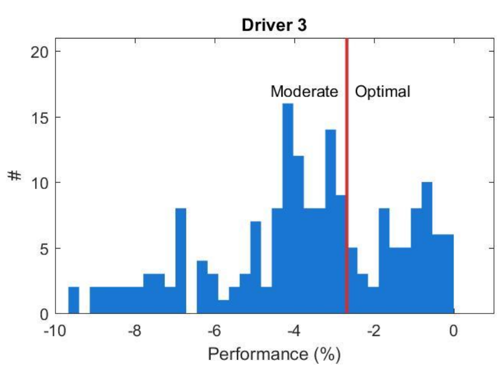

Figure 2. Histogram the performance scores of driver 3. Red line indicates individual performance threshold, categorizing performance as optimal and moderate.

Using the above procedure, three performance categories are defined based on the performance scores and stress levels:

1. Optimal performance (OP)
2. Moderate performance with stress level below the optimal stress (Mo/B) and
3. Moderate performance with stress level above the optimal stress (Mo/A).

An example is shown in Figure 3

D. Data Analysis

For each driver, the probabilistic method of Kamata et al. [2] is used to determine the Individual Focus Zone (IFZ) for each participant.

Two logistic regression models for binary classification are estimated using the Newton-Raphson method. The outcome variable in the first model is 0 for Mo/B and 1 for OP or Mo/A and describes the probability of optimal performance or moderate performance above optimal stress, defined as P_1. The outcome variable in the second model is 0 for Mo/B or OP and 1 for Mo/A and describes the probability of moderate performance above optimal stress, defined as P_2.

Given a stress level, the probability on the three performance categories is calculated:

1. $1 - P_1$ describes the probability on moderate performance below optimal stress
2. $P_1 - P_2$ describes the probability on optimal performance
3. P_2 describes the probability on moderate performance above optimal stress.

An Individual Focus Zone is defined as the zone of stress within which each driver has a higher probability of optimal performance than moderate performance. Three Individual Stress Zones can then be distinguished; distracted, when stress is below IFZ, focused, when stress is in IFZ and distressed, when stress is above IFZ.

One-way ANOVA is used to test for significant differences in performance scores between Individual Stress Zones. Tukey-HSD post-hoc test is used if 1-way ANOVA

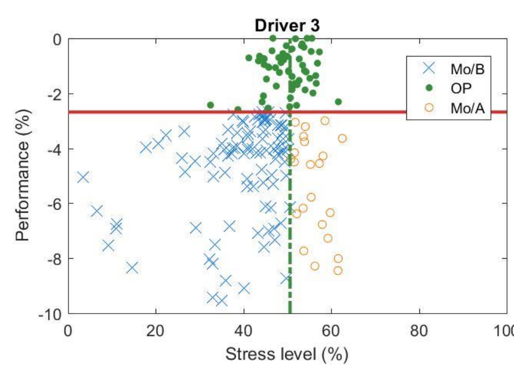

Figure 3. Three performance categories (optimal performance (OP), moderate performance below (Mo/B) and above (Mo/A) optimal stress defined by performance score and stress level for driver 3. Individual performance threshold (red line) and median stress level of optimal performance (dashed green line) are also shown.

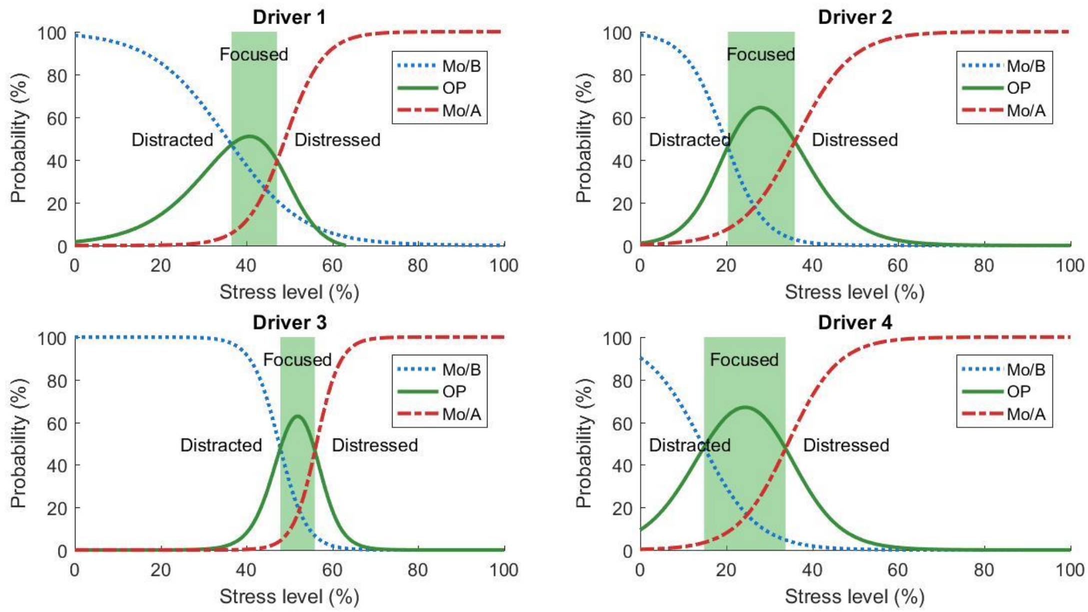

Figure 4. Probability curves for moderate performance below optimal stress (Mo/B), optimal performance (OP) and moderate performance above optimal stress (Mo/A). Individual Focus Zone is shown as shaded area. Individual Stress Zones (distracted, focused and distressed) are also visualized.

shows significant results. Analysis was done in Matlab (R2013b, The MathWorks Inc, USA).

III. Results

A. Individual Stress Zones

As mentioned above, to determine the Individual Stress Zones (ISZ), logistic regression is performed on stress using performance categories as dependent variable for each driver.

An overview of the performance category probability curves is given in Figure 4 for all drivers. The horizontal axes represent the drivers' stress level during the race, where the vertical axes represent the probability of a specific performance category. The IFZ is within the range of 36.5 – 47.1% for driver 1, 20.4 – 35.9% for driver 2, 47.9 – 55.9% for driver 3 and 14.9 – 33.8% for driver 4. The corresponding maximal probabilities on optimal performance are 0.51, 0.65, 0.63 and 0.67 for drivers 1 to 4 respectively.

The range of IFZ is determined based on a probability for optimal performance being higher than the probability for moderate performance. The range of distracted corresponds with stress below IFZ, and the range of distressed corresponds with stress above IFZ.

B. Performance in stress zones

The influence of ISZ on performance scores is investigated, by comparing performance between ISZ. For each driver 1-way-ANOVA is performed. If the p-value indicates significant differences ($p < 0.05$) between at least 1 group compared to the others, a Tukey-HSD post hoc test is performed. An overview of this analysis is given in Table 1.

For driver 1 no significant differences in performance are found between the ISZ, although performance when the driver is focused tends to be slightly better than when he is distracted or distressed.

Drivers 2, 3 and 4 all perform significantly worse when distressed, compared to being distracted or focused. Performance scores decreased on average with 1.5%, 3.2% and 2.1% compared to focused for drivers 2, 3 and 4 respectively.

Driver 3 performs significantly better when focused than when he is distracted. His performance score decreased on

Table 1. Overview of sector performance (Number of sectors, Avg. ± SD) in the 3 individual stress zones, per driver. ANOVA p value indicates significant differences ($p < 0.05$) between performance in ISZ, [123] show significant differences ($p < 0.05$) with distracted, focused or distressed respectively. Performance that is more negative, indicates slower sector times compared to personal best.

	Distracted		Focused		Distressed		
	N	*Performance (%)*	*N*	*Performance (%)*	*N*	*Performance (%)*	*ANOVA*
Driver 1	83	-2,2 ± 1,6	65	-2,0 ± 1,9	57	-2,8 ± 3,2	p = 0,13
Driver 2	58	-1,5 ± 0,9 [3]	60	-1,2 ± 1,0 [3]	140	-2,7 ± 2,6 [12]	p < 0,01
Driver 3	100	-4,3 ± 2,3 [23]	64	-2,6 ± 2,1 [13]	18	-5,8 ± 4,0 [12]	p < 0,01
Driver 4	5	-1,2 ± 0,5 [3]	76	-2,4 ± 2,0 [3]	134	-4,5 ± 2,5 [12]	p < 0,01

average with 1.7%, Driver 2 also tends to perform better when focused, but this is not significant for distraction. Driver 4 on the other hand tends to perform better when distracted.

Driver 3 is distressed in only 18 sectors of the 182 he drove. Driver 4 is distracted in only 5 sectors of a total 215.

IV. Discussion

An individual Focus Zone where the probability on optimal performance is larger than moderate performance, is calculated for each driver. Accordingly, three Individual Stress Zones (distracted, focused and distressed) are distinguished per driver. These zones are different for each driver, and show the need for an individual approach.

Sector performance tends to be better when the driver is focused, compared to distracted or distressed. For 3 out of 4 drivers, performance scores are significantly better when focused than when distressed. For 1 out of 4 drivers, performance scores are significantly better when focused than when distracted.

Different driver profiles can be distinguished from the data. Sector performance in all stress zones shows that drivers 1 and 2 are more consistent than drivers 3 and 4. Driver 3 is mainly distracted or focused while driving, where driver 4 is either focused or distressed.

An important limitation to this study, is that the 3 different sectors on the track are considered equally. However, both driver performance and stress are influenced by the part of the track they are driving. Some parts require more skill than others, and may affect how the driver is coping with this. There are additional external influences on driver performance and stress that are not considered here, such as weather conditions, tire wear, fuel consumption, battling and/or overtaking opponents.

V. Conclusion

Using an optical heart-rate sensor on the wrist and the internal sensors of a smartphone, the stress level of four drivers is successfully monitored in real-time during a 10hr race. The objectives of this study are to identify Individual Stress Zones, and evaluate driver performance in these ISZ.

Individual Stress Zones are calculated per driver, distinguishing mental states of distraction, focus and distress from one another.

Performance is analyzed in function of these Individual Stress Zones, showing better performance when the driver is focused, than when the driver is distracted or distressed. Being too calm or too stressed thus may lead to inferior performance.

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