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Arousal effects on Fitness-to-Drive assessment: algorithms and experiments

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***Abstract*—Several elements can affect the drivers' behaviour while they are performing driving activities. Ranging from visual to cognitive distractions, emotions and other drivers' conditions (that could emerge from biometric data, such as temperature, heartbeat, pressure, etc.) can play a significant role, performing as a factor that can increase drivers' response time. This could be crucial in avoiding dangerous situations and in deciding and performing actions that could influence the happening of car accidents. This paper introduces the concept of the "Fitness-to-Drive" index and aims to evaluate how the arousal effects can influence the drivers' status. The paper presents some experimental evaluations we have conducted on a driver simulator, discussing the obtained results.**

***Index Terms*—Drivers' behaviour, Driving simulation, Arousal Monitoring, Experimental evaluations**

I. Introduction

Nowadays, we are overwhelmed by different and many external stimuli from a wide range of sources that could trigger our reactions, making us think, decide, and, sometimes, draw conclusions and making judgments [1], [2]. This could provide significant consequences, among which distraction from the goal we were working on, and also an altered mood and felt emotions [3]. It is worth mentioning that similar repercussions are not acceptable in those contexts where a very high level of reactivity is essential, where the response time to not predictable events is crucial. In this sense, a typical example is represented by the conditions and the contexts that can affect our attention and behaviors while we are driving a vehicle. Some studies, with experiments in real scenarios, reported response time as around 1 second, as per the time requested to brake after the perception of an obstacle and the evaluation of the situation, where a braking is needed [4]. In this context, any distraction or any kind of afterthought (that could be even introduced by any emotion) could significantly increase the time window of the driver's intervention on the vehicle, eventually causing fatal consequences too. Data recorded from car accidents show that driver's distraction during the driving activities is a key element. In fact, according to official statistics [5], drivers who use cell phones have almost 4 time the possibility of being involved in a car accident, compared with the ones who do not use mobile devices while driving. Other situations and elements which can affect the drivers' conditions are psychophysical alternations and tiredness [6], together with the high speed and the non-compliance to the traffic laws and the security measures.

The goal of the work presented in this paper is to define those elements that can concur in affecting drivers' behaviours: i.e., visual and cognitive distractions, drivers' emotions and arousal, together with other driving elements (such as high speed and non-compliance to the correct rules), so as to compute an index that could be exploited in identifying the so-called "Fitness-to-drive". In particular, we will focus our attention to how the arousal could affect such fitness-to-drive assessment. A specific attention will be devoted to the experimental evaluation of the arousal identification and computation. The experiments where conducted with a driving simulation and the results will be reported in this paper.

The rest of the paper is structured as follows. Section II presents main related work, providing details about the Arousal, its measurement and the Valence. Section III presents the Methodology, describing how the Fitness-to-Drive could be computed and which is the role of the Arousal in such a computation. Section IV describes the experimental evaluation that has been conducted and reports the obtained results. Finally, Section V concludes the paper with some final remarks.

II. Related works

Psychology is defined as "the science that studies psychic, conscious and unconscious, cognitive (perception, attention, memory, language, thought, etc.) and dynamic (emotions, motivations, personality, etc.) processes" [7].

Emotions can thus be defined as *"organized and complex patterns of physiological responses (necessary to prepare the body for a rapid behavioral response), of facial expressiveness (with a communicative and social value of sharing experience with our peers), cognitive processing (i.e. rational analysis*

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of the situation and context) and subjective emotional experience" [8].

According to Russell's dimensional theory [9], any emotional experience can be represented by a linear combination of *Arousal* (Intensity with which an emotion is felt) and *Valence* (Pleasantness of an emotion, ranging from pleasant to unpleasant), quantities that will be explored later.
Another factor to consider is Davidson's approach-departure model [10]:

- Emotions such as anger, happiness or surprise are characterized by a motivational drive towards the object that produced them.
- Emotions such as fear, disgust or sadness share among them a propensity to avoid the object and / or the situation that triggered them.

Furthermore, it is right to underline how emotions influence both cognitive aspects and the perception of the world, and vice versa. For example, if you are happy, you will also be more willing to approve and more open to other people. On the contrary, when we are angry, even the mere presence of other individuals could worsen our mood.
In general, however, it can be observed that:

- Negative emotions restrict the focus of attention, helping to analyze the danger of an event, without understanding the whole situation.
- Positive emotions expand attention, creativity and the ability to memorize information, being able to perceive more stimuli from the environment, but without focusing on one in particular.

This leads to the affirmation that any perceived emotional state will be deleterious for concentration, precisely because it adds a filter that influences the vision of reality. *Neutrality* is therefore identified as an emotion to avoid perception alterations, useful when you need to perform delicate tasks where particular attention is required.

In the literature there are numerous researchers who have devoted a lot of time to the study of emotions, including Paul Ekman, Robert Plutchik and Jaak Panksepp with thoughts not strictly in agreement, which will be discussed below.

According to what Paul Ekman reported in his studies [11], it is possible to identify "basic emotions" , i.e., recurrent characterizations that occur in an individual, upon the occurrence of events, such as the happiness expressed in receiving food, or the fear addressed to an imminent danger.

The identified list is the following: (i) Happiness; (ii) Fear; (iii) Anger; (iv) Sadness; (v) Surprise; (vi) Disgust. These emotions are so defined precisely because they can be linked to facial expressions displayed by individuals from very different cultures [12]. From this it is clear that this phenomenon is of innate origin and influences the process of cultural development, on a biological level. By observing the model of newborns, one can immediately understand the behavior inherent in their nature: the smile as an expression of happiness (all needs are met), or the cry to indicate that there is a lack to fill.

The previously presented list is then accompanied by emotions defined as "derivative", that is, attributable to the primary ones, but with slight nuances and overlaps between them. The list includes: fun, satisfaction, contempt, contentment, embarrassment, excitement, guilt, relief, sensory pleasure, shame. In this case, a real distinction between one case series and another would be more complicated, making the classification more complex starting from the facial expression.

A similar study is the one presented by Robert Plutchik [13]. To the 6 basic emotions previously introduced, expectation and trust are added, so as to have a total of 8. Once arranged in a circle, placing the complementary ones at the antipodes, they are subsequently added [13].

A. Arousal

Arousal (or arousal) is defined as a "general state of activation and reactivity of the nervous system, in response to internal (subjective) or external (environmental and social) stimuli" [8].

When the value is compared with the performance of an activity, as shown in Fig. 1, an inverted U relationship is generated, where the point of maximum performance is observed at the vertex of the curve. Moving away from the ideal point, either by increasing or decreasing the arousal value, the performance will decrease.

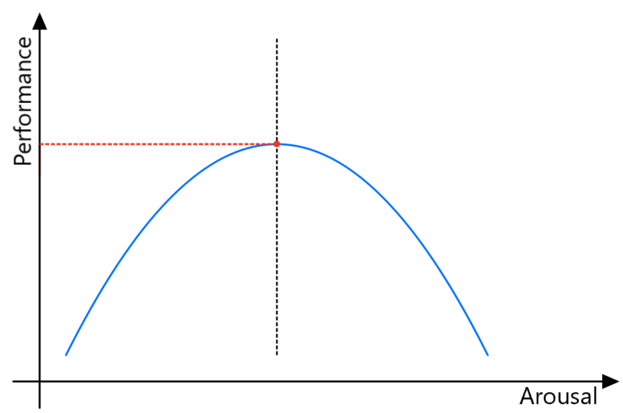

Fig. 1. Relationship between Arousal and Performance

The curve shown in the Fig. 1 draws an ideal, symbolic relationship, while in reality, curves of different nature are found, precisely because they vary from person to person and are influenced by different aspects, including: ability level; personality; degree of anxiety; complexity of the task.

Precisely with regard to the last point of the list it is possible to observe how the degree of complexity of a task, even if it is an external factor, affects the graph of the relationship. In fact, by identifying 3 possible activities that involve the individual in a different way, a different arousal value is required to maintain an adequate level of performance for carrying out the task. For example, making photocopies requires a lower level than driving a car, which in turn is less than a surgical operation.

The law of Yerkes and Dodson argues that performance and arousal are directly related and that high levels of arousal can even improve performance [14].

All this up to a certain point, however: if the levels become too high, the opposite effect is had, with the consequent decrease in performance. Two phases can therefore be identified, which can be observed in Fig. 1:

1) The ascending part of the curve can be considered as an energizing effect for the realization of the activity to perform
2) The descending part shows an excess of excitement, followed by the relative negative effects on the activity that is being sustained, such as stress, anxiety etc.

On a psychological level, the anxiety you feel before a task can help you focus on the goal to be achieved in the test to be taken, helping to remember information related to what you have studied, however, if the stress is too much, you have a opposite effect, compromising concentration and making it difficult to remember concepts.

On the physical level, on the other hand, a right degree of arousal allows the secretion of adrenaline, which leads the athlete to improve their performance, but, by accessing the correct threshold, there could be reverse effects, generating discomfort and confusing those who are supporting. the activity.

Driving a car along certain stretches of road or a "car-following" situation result in monotonous actions, compromising concentration. A study related to this specific context, compared the performance of drivers, with and without music [15] It has been shown that listening to a song does not affect accuracy while driving, but on the contrary, in the presence of a song, better latencies were found during acceleration and braking, in the presence of a higher arousal.

B. Arousal measurement

Numerous methods have been applied in the literature for the assessment of arousal and valence:

1) Heartbeat: One method for the detection of arousal is the analysis of the variation of the heartbeat. According to what is reported in the following study [16], it is possible to evaluate the level of arousal, in correlation with other parameters taken into consideration in the methods listed below.

2) Electroencephalogram and Electromyography: The electroencephalogram (EEG) is the non-invasive recording of the electrical activity of the brain using external electrodes. The detected electrical activity is represented by a series of waves reproduced on a screen and then printed on paper or transferred to an electronic medium. Electromyography (EMG) is a diagnostic test that allows you to study the functionality of the muscles and connected nerves present in a given area of the body. These measures were used for carrying out studies in which valence had to be assessed [17], [18].

3) Pupillary analysis: Another method used for making arousal and valence measurements is to take into account the diameter of the pupil and its dilation [16].

A study [19] showed that, when viewing emotionally significant images, the variation in the pupil size of the subjects was identified, thus finding a correlation with emotionally engaging stimuli.

It has been observed that with this method the valence is not detected, in fact both pleasant and unpleasant stresses produce the same change. Furthermore, as rightly observed in the study, attention must be paid to light fluctuations during sampling, in fact the latter would cause an unwanted change in the pupils diameter in order to detect arousal.

4) Conductance of the skin: One method used for measuring arousal is the analysis of skin conductance

One study found that sympathetic arousal is an effective technique for measuring this magnitude, better than conventional measures [20].

5) Facial temperature: Through the measurement of the variation of the facial temperature it is possible to evaluate a change in arousal.

In particular, it can be seen how infrared thermal imaging is a valid technique for calculating this value [21].
The affected facial areas mainly concern the nose. This method also provides the possibility of detection using a thermal imaging camera, so as to reduce the discomfort that skin sensors could introduce.

Following the analysis carried out on the various methodologies proposed, it must be emphasized that the tools used can influence the surveys by establishing bias and altering the truthfulness of the data collected. In fact, a device placed on the body could put the candidate in awe, creating discomfort. For this reason, we should aim for tools that are less overrun as possible.

C. Valence

The hedonic valence (or hedonic tonality) refers to the pleasantness or unpleasantness of the emotional experience (positive or negative hedonic valence) for the subject who is experiencing it [8]. Emotions can be divided into two categories:

- *Positive valence*: excitement, joy, happiness, contentment, relaxation, calm.
- *Negative valence*: tension, anger, stress, sadness, depression, boredom

In contrast to the considerations made previously for arousal, it is not possible to identify the "right" value for the correct performance of an activity, but it will be analyzed situation by situation. For example, during a driving session you are influenced by emotions and it can be said that anger increases the risks you run [22](e.g. you tend to cross the orange light more if you are angry), while if you are experiencing a sensation of calm you will be able to proceed in a better way, by controlling the vehicle more.

It should be emphasized, however, that if the comfort is too high, it is possible to lead to a decrease in attention, with all the consequences of the case.

In addition, a study was conducted [23], as opposed to the one analyzed previously, where it is shown that cheerful music distracted the drivers more by decreasing the average speed of travel and worsening the alignment in the lane.

III. Methodology

The *Fitness to Drive (FtD)* is defined as "the ability to drive safely without problems caused by physical ability, injury, medical or mental health" [24]. The calculation of the Fitness to Drive index aims at a constant evaluation of the driver, during the entire driving period, analyzing the physical, psychological and emotional state. We can think that the value of Fitness to Drive, it is influenced by several factors: *visual distraction*, *cognitive distraction*, *emotions* of the driver. We can assume that the general formula of the FtD is:

$$\mathbf{FtD} = \begin{cases} 1 - (\mathbf{CD}_i + \mathbf{VD}_i + \mathbf{EA}_i) & \text{if } (\mathrm{CD}_i + \mathrm{VD}_i + \mathrm{EA}_i) < 1 \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

The formula indicates that the Fitness to Drive index value is a value between 0 and 1. Low values indicate a high probability of making mistakes while driving. The parameters used in the formula are respectively:

- $\mathbf{DC}_i$: indicates the value of cognitive distraction at the i-th instant
- $\mathbf{DV}_i$: indicates the value of visual distraction at the i-th instant
- $\mathbf{EA}_i$: indicates the value of emotions at the i-th instant weighted by the arousal value.

In our work we focus on the effect of emotions and arousal in calculating the FtD.

A. Algorithm

In the definition of the EA_i factor, Ekman's basic emotions were taken into consideration, with weights assigned in relation to previous work and analysis of the state of the art. The resulting formula is the following:

$$\mathbf{EA}_i = \mathrm{A} * \frac{\sum_e p_e * e}{\sum_e p_e} \quad (2)$$

Where:

- $\mathbf{A}$: arousal value between 0 (optimal value) e 1 (arousal low or high)
- e: emotion intensity
- p_e: emotion weight as in Table I

TABLE I
Emotions' weights

Emotion	Weight
Anger	25%
Happiness	25%
Fear	16.7%
Sadness	16.7%
Disgust	8.3%
Surprise	8.3%
Neutral	0

The value thus evaluated reduces the incidence of emotions during the Fitness to Drive calculation when you have a good level of arousal, precisely to highlight the possibility of being able to manage the emotion you are experiencing.

If the Arousal level is 0 (optimal state for driving a vehicle), since it is a multiplicative factor for the calculation of the emotion factor, it will bring this value to 0, so as to avoid their negative impact on the FtD. On the contrary, in the case of arousal equal to 1 (worst state to drive a vehicle), the maximum negative impact of emotion on the FtD will be found. It is possible to observe in Fig. 2 how the FtD index varies, influenced only by the value of emotions, with a transition from the arousal value from optimal to worst state.
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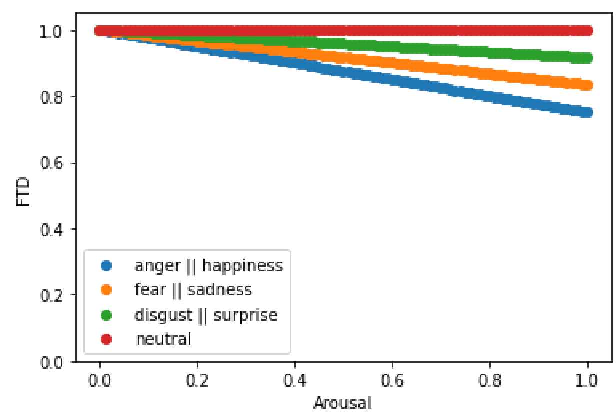

Fig. 2. Arousal impact on new FtD formula

IV. Experimental evaluation

In order to verify the effect of arousal and emotions on FtD, we have defined a series of reproducible tests so that a general result can be extracted. During a driving simulation, participants are asked to perform five different tasks, each one associated with a related test phase. Each test phase is aimed at collecting data about the participant state in terms of arousal and emotion under specific circumstances. We then used a classifier for emotions and a software for the evaluation of the arousal on the subjects during the driving simulation.

A. Test definition

Five phases lasting 3 minutes each were identified, each of which is associated with the execution of a specific task:

1) **Car following**: the candidate follows the machine in front of him for the indicated time. This phase allows for measuring the state of the participant during the execution of a relatively simple car following task without further sources of excitement or of distraction.
2) **Car following with music**: the candidate follows the machine in front of him for the indicated time, listening to a song at will. The song chosen by the candidate is used as a stimulus to induce a pleasant emotion that

is supposed to alter the participant's state during the execution of the car following task.

3) **Free drive**: the candidate drives freely for the indicated time. This phase is needed to create a baseline against which to compare the data collected in the other phases.
4) **Car following with memory task**: the candidate follows the machine that is in front of him for the indicated time, having to answer questions put to him, selected from the following list:
    a) What did you have for breakfast?
    b) What did you eat at dinner?
    c) Last watched movie.
    d) Last result of the team supported.
    e) Bedtime last night.
    f) Last book read.
    g) Last song listened to.
    h) Divine comedy author.
    i) 22 x 4.
    j) 15 + 18.
    k) 21 - 4.
    l) 1/2 + 1/4.
    m) Phone model.
    n) Model of the car.
    o) Browser you usually use.

    Such a solution accomplishes to involve the participant, during the car following, in a secondary mental task inducing cognitive distraction, while letting the subject keep the eyes on the road.
5) **Car following with visual distraction**: the candidate follows the machine in front of him for the indicated time while having to listen to a sequence of city names that the participant has to write on a smartphone. This way, the participant is asked to perform the car following task being visually distracted.

When designing a data collection campaign involving human participants under different conditions, attention should be paid to the influence that the ordering of the different conditions may have on the collected data. For example, performing the simple car following task before the car following task with music may create a learning effect that makes it easier for the participant to do the car following task while listening to the music. As another example, the emotion experienced in the car following session with music may "trespass" into the subsequent free driving session, which would then become a driving session in a non-neutral emotional condition. To mitigate these known effects and collect more robust data, it is an established practice of experimental psychology to divide participants into experimental groups, where each group is characterized by a distinct ordering of the various phases. In this study, we report the results of the analysis of the first experimental group in which the test phases were arranged in the order with which they are presented in this section.

B. Testbed deployment

We used a MacBook Pro, on which the processes for the classification of emotions and the calculation of the FtD are performed by aggregating the arousal data calculated on a FitBit Sense smartwatch [25]. As a driving simulator we used Carla [26] on a dedicated PC with a high-performance GPU. For our experimentation we used an emotion classifier already trained and present in the literature [27]. This is because our aim is to verify if and how much arousal affects driving. To use FitBit Sense we created an app running on the smartwatch combined with another app running on the smartphone.

Before the test, the basic heart rate was measured for a time of 60 seconds through the special application created for Fitbit. Subsequently, the candidates were given time to get used to the driving simulator, after which the test began. During the simulation 28004 samples were collected (approximately 1 per second). Thirteen participants (4 females and 9 males) were involved, all with driving licenses. The age is between 20 and 24 years, with an average of 21.3 years. A heart rate was found in the range of 70 to 98 bpm, with an average of 81 bpm.

C. Results

A first analysis of the values can be found in Table II. As for the Fitness to Drive value, it ranged over the entire range of values it could assume (not calculating cognitive and visual distraction), with an average very close to the maximum value. The arousal value, see table, has also spanned the entire range of possible values. Furthermore, its mean is close to the optimal value (0) and, considering the standard deviation, it rarely happens that 50% is exceeded, just as expected in fact, the candidates were focused and without emotional shock during the test. Finally, the speed value is consistent with the route traveled, being an urban road with traffic lights, roundabouts and intersections and having to carry out car-following for most of the test.

TABLE II
TEST STATISTICS

	Mean	SD	Min	Max
FtD	0.965	0.05	0.75	1
Arousal	0.21	0.27	0	1
Speed	18.2	18.6	0	107.5

We tried to check for some correlation between the data once aggregated. The samples, performed approximately every second, were labeled as "error" if they were within T seconds of an infraction reported by the simulator.

As can be seen, for example, in Fig. 3, we can find a negative correlation in *Fitness to Drive-errors*, while a positive correlation in *arousal-errors* and *speed-errors* , as expected from the premises. Figure 4 shows the fluctuations in the FtD index caused by the different emotional states combined with the arousal value. We can see how the driving errors occur in correspondence with minima of the index FtD.

V. CONCLUSION

This paper introduces the concept of the "Fitness-to-Drive" index, computed on the basis of those elements that can concur in influencing drivers' behaviours, such as visual and cognitive distractions, drivers' emotions and his/her arousal. In

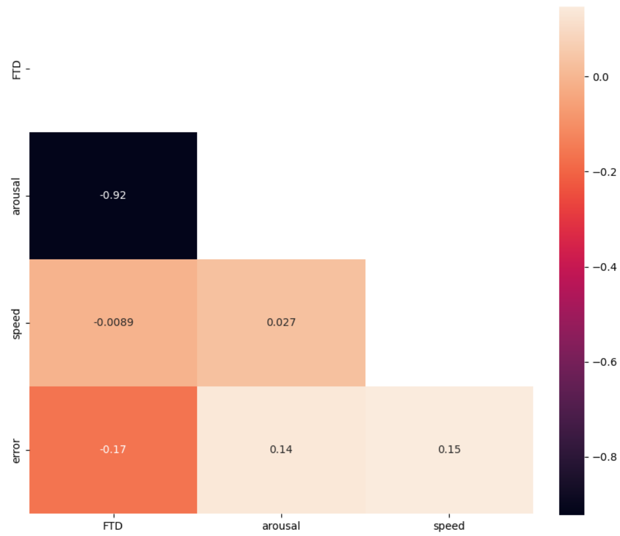

Fig. 3. Correlation of data with driving error.

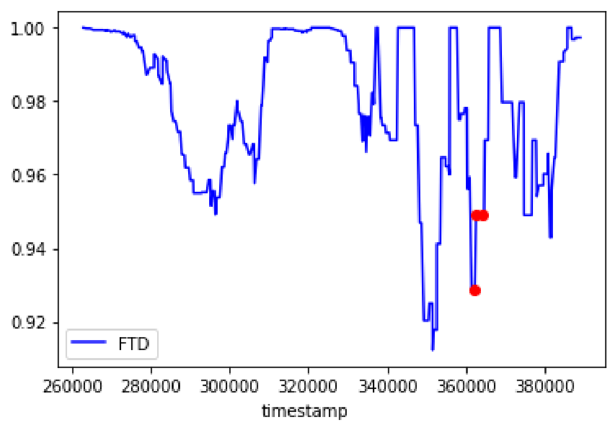

Fig. 4. A simulator session. The red dots are driving mistakes.

particular, our aim here has been to evaluate how the arousal effects can influence the drivers' status and how they can affect such Fitness-to-drive assessment. The paper presents some experimental evaluations we have conducted on a driver simulator, discussing the obtained results.

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