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How is the Driver's Workload Influenced by the Road Environment?

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Abstract

This paper focuses on the study of the driver's workload while driving on a rural two-lane road with different traffic flows. The aim of the research is to examine a parameter that could be representative of the driving effort, quite sensible to the external factors that cause disturbance to the regular driving activity. To solve this problem, the authors used a specific instrumented vehicle for monitoring some physiological parameters of the driver (as the eye movements and the Galvanic Skin Resistance), referring their values to the road context. The results are very interesting and confirm that knowing the workload is useful to improve the road safety only if it is related to the external context, as well as road geometry, traffic, visibility, etc. Only in this way, the road administrators can deduce proper information to plan and direct accurate and productive upgrade working operations.

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Keywords: workload, road context, visual behaviour, galvanic skin response

1. Introduction

In a complex system, as the road, the Workload (WL) can describe properly and synthetically the human component, as it includes the driver's relationships with the vehicle and the external environment. In a very simple

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way and according to [1], the WL may be defined as the quantity of capacity used by the driver to perform a specific task. In theory, we may state that there is some stimulus coming from the external environment, to which the user responds according to his own ability [2–5].

In particular, the Mental Workload (MWL) is more complex to analyze, as it depends on both subjective characteristics of the user – such as ability, experience, age, fatigue, drug use, etc – and other elements of the external context – such as road, traffic flows, vehicle ergonomics, its automation [6–9].

In very simple but effective, the numerous methodologies proposed in the last years to quantify the MWL [10] can be classified in three main categories:

- Performance measurements;
- Subjective measurements, based on the effort perceived by the user;
- Physiological measurements.

The studies on the eye movements can be included in the last group, and many authors believe that they may be well related to the MWL [1, 11–14]. In detail, these measurements are deduced by the fixation time, the saccade length, the latency and duration of the eye blink, the pupil dilation [15–17].

Using other physiological variables, such as the Electroencephalography (EEG), the Electrooculography (EOG), the dermal conductivity evaluated through measurements of the Galvanic Skin Response (GSR), and the Heart Rate, produced good results, but their role in determining the MWL is controversial and should be properly deepened [3, 9–10, 18–19]. In order to avoid “false positives”, these variables have been included simultaneously, determining a remarkable analytical complexity in the model definition [20–21].

In order to be effectively helpful in the road sector, the researches have to clarify how the MWL may be related to the different activities that the road administrators can adopt to reduce the driving hazard. It is known, indeed, that all the elements in the road context are not equally important when the driver acquires and processes the visual information [22–23].

Consequently, the authors believe that some limits evidenced in the previous analysis should be overpassed. The WL definition of a driver or a class of drivers has to be referred to the related scenario in which they are driving. The more detailed the scenario, the more accurate the intervention and the improvement by the road administrators. They can actually modify or adequate the aspects causing an excessive WL for users by means of proper corrective actions. This is not easy, because geometrical elements or traffic disturbances cannot preliminarily classified by the analyst, but they should be evaluated according to the related importance for the drivers. For this reason, by examining the driver’s visual strategies and a physiological measure of WL, this paper aims to consider the external factors causing WL, in order to mitigate or delete them, without focusing on identifying the related tolerance boundary value.

2. Methodology

The basic idea of the research is to correlate the driver’s visual behavior, in terms of fixations and saccades, and the measurements of Galvanic Skin Response (GSR), to identify elements in the visual frame determining a high load on the driver. For doing this, the authors designed an original instrumentation, based on an Arduino ® microprocessor and various commercial sensors, such as a GSR meter, a GPS, an inertial system including accelerometers and gyroscopes to calculate the steer rotation and the driver’s head movements. Another specific device has been adopted for the tests, in synchrony with the others, to acquire the visual activity of the driver: the Tobii Glasses ®. The simultaneous management of these instrumentations can be performed through a particular software, properly coded to control and synchronize in real-time the sensor measurements. Using an OBD port, the notebook can also download telemetry data from the vehicle electrical box.

The decision to use a real vehicle is due to the aim to analyze reactions to stresses not preliminary known, in terms of typology and position, in order to favour a natural behavior of the driver, although he knows he is performing a scientific test. However, the authors think that comparisons with other results obtained in a driving simulated environment can be very productive and interesting.

The trials took place on a two lane rural road, called SS113, closing to the town of Messina (Italy) over a distance of about 11 km with a consistent cross section and under normal traffic conditions. The tests were performed with three different drivers and have been characterized by homogeneous conditions in terms of traffic flows (time of tests 09.00–12.00) and weather. The drivers were made up of males between the ages of 30 and 35 with at least 10 years' driving experience, all habitual users of the road under examination.

According to the authors, in this preliminary phase of the research, there was not a need to consider a larger group of drivers, since the aim is to verify eventual correlations between disturbing elements in the visual frame and the MWL, avoiding temptations to produce hastily statistical laws of dubious value, reliability, and repeatability. Generalization can be investigated in future works, if the correlation is evidenced.

Considering the disturbing elements, since they are not equivalent and equally relevant, the authors have classified them in two great classes (statics and dynamics) and in different typology groups:

Static Objects:

- Parked vehicles,
- Rubbish bins,
- Signage,
- Working areas,
- Cockpit.

Dynamic Objects:

- Cars moving in the opposite direction,
- Bicycles moving in the opposite direction,
- Motorcycles moving in the opposite direction,
- Cars moving in the same direction,
- Bicycles moving in the same direction,
- Motorcycles moving in the same direction,
- Pedestrians.

The eye-tracker can allow the authors to identify which objects in the visual frame and for how long the driver focuses on while driving. The observation time is considered in percentage, as ratio between the fixation time and the time in which the object is actually present in the visual frame. If this ratio is small (or equal to zero), it means that the driver considered of little importance (or not important at all) acquiring information coming from that object. Actually, when various stimuli are simultaneously in the visual frame, a particularly overloaded user might choose to focus on the most significant element, discarding the others.

Considering the dermal conductivity measurement, the adopted device provides values in micro Siemens with a sampling frequency of 1 second. Examining the trend of this variable in the post-processing phase evidenced some relevant peaks, that can be ideally represented in Fig. 1.

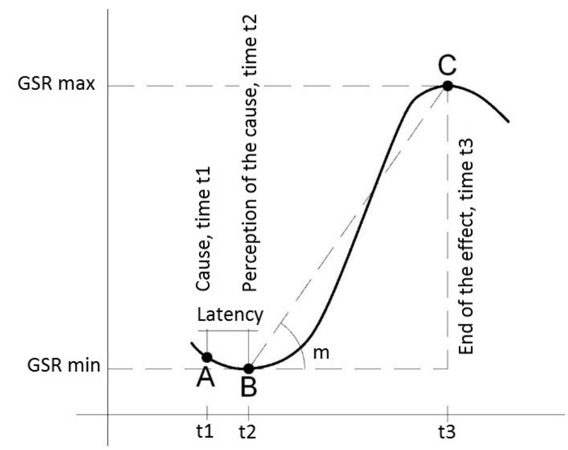

Fig. 1. Schematic trend of the GSR function.

This representation is very helpful to define some specific indices that can be adopted for easily considering the GSR measurements. In particular, the point A is related to the time t1, when the external stimulus appears in the visual frame. The related reaction is not immediately perceived, so that the GSR function decreases to the point B. This point coincides with the time t2 in which the negative effects of the disturbing elements starts. The negative effects continues up to the point C, corresponding to the time t3, after which the user tends to recover his starting dermal conductivity.

Knowing the position of the points A, B, C in terms of GSR and time can be used to calculate the angular coefficient m, representing a measurement of the ease or difficulty of recovery the initial condition after the stress. This parameter can also be considered as a resilient index for the user. However, in the real situations, it is possible to notice different subsequent causes in series that prevent the GSR recovery and, on the contrary, can cause its growth.

The integral subtended by the GSR represents a cumulative function over time that can be considered as a very reliable MWL measurements, with an increasing trend maintaining memory of the effort spent by the driver since the beginning of the test.

3. Results

The analysis of data coming from the eye tracker allowed the authors to identify the disturbing elements which the driver's eyes focused on, compared to a condition of isolated vehicle. In particular, the authors calculated the fixation time for each object and the total time during which they were present inside the visual frame.

As previously said, it is more significant to separate in different classes the various objects seen in the visual frame, to evidence eventual specific troubles with particular kind of objects. For this reason, in Tab. 1 the authors listed for each static object seen while driving (col. 1) the fixation times (col. 2), the total time during which they were in the visual frame (col. 3), and the ratio between these times (col. 4), providing a quantification of the relevance given to the object by the driver. Tab. 2 is similar to the previous one, but it represents the dynamic objects.

Table 1. Percentage fixation time of static objects related to the time during which they are inside the visual frame.

Static Object	Fixation Time (s)	Inside Visual Field Time (s)	%
Parked vehicles	108.63	442.67	24.54
Dumpsters	57.37	291.30	19.69
Vertical road sign	8.33	113.77	7.32
Road yard	0.30	5.33	5.63
Cockpit	4.00	2.37	59.17

Table 2. Percentage fixation time of dynamic objects related to the time during which they are inside the visual frame.

Dynamic Object	Fixation Time (s)	Inside Visual Field Time (s)	%
Vehicles in opposite direction	7.63	309.70	2.46
Cyclists in opposite direction	20.43	48.50	42.13
Motorcycles in opposite direction	0.63	18.83	3.36
Vehicles in the same direction	63.20	172.40	36.66
Cyclists in the same direction	120.67	204.87	58.90
Motorcycles in the same direction	2.13	12.80	16.67
Pedestrians	3.73	35.07	10.65

Regarding the dermal conductivity measurements, all the main GSR local maxima (measured in micro Siemens) are related to an effective cause. For each cause, the point A, B, and C are identified and some specific indices are calculated (Tab. 3–5). Fig. 2 represents the trend of the GSR for the three different test performed in the research.

Fig. 3, instead, shows the integral of the GSR function, assumed as the trend of the MWL. The three curves are related to the three different tests.

Table 3. GSR measurements for driver 1.

Peak	Trouble	Cod.	GSRmin (µSiemens)	GSRmax (µSiemens)	ΔGSR (µSiemens)	Δt (second)	m	Latency (second)
1	Static	1	3.027	3.104	0.08	1.80	0.04278	1.89
2	Static	1	2.952	2.987	0.04	2.76	0.01268	0.66
3	Edge		3.042	3.112	0.07	3.57	0.01961	0.45
4	Curve right		3.086	3.142	0.06	3.72	0.01505	1.44
5	Curve right		3.070	3.162	0.09	2.82	0.03262	2.16
6	Curve right		3.063	3.147	0.08	3.90	0.02154	2.04
7	Curve right		3.063	3.116	0.05	2.34	0.02265	1.89
8	Curve right		e3.314	3.456	0.14	5.52	0.02572	1.77
9	Dynamic	2	3.407	3.502	0.09	5.79	0.01641	1.32
10	Dynamic	5	3.432	3.627	0.20	6.27	0.03110	3.60
11	Curve right		3.496	3.648	0.15	15.78	0.00963	3.99
12	Dynamic	5	3.729	3.813	0.08	5.52	0.01522	3.39
13	Dynamic	5	3.815	3.841	0.03	1.11	0.02342	10.74
14	Dynamic	1	3.611	3.735	0.12	7.98	0.01554	1.29

Table 4. GSR measurements for driver 2.

Peak	Trouble	Cod.	GSRmin (µSiemens)	GSRmax (µSiemens)	ΔGSR (µSiemens)	Δt (second)	m	Latency (second)
1	Dynamic	1	4.064	5.135	1.07	24.99	0.04286	3.48
2	Dynamic	2	4.920	4.994	0.07	1.68	0.04405	0.75
3	Static	1	4.652	4.806	0.15	6.18	0.02492	2.31
4	Edge		3.823	4.240	0.42	17.85	0.02336	2.19
5	Edge		3.999	4.170	0.17	9.90	0.01727	1.14
6	Static	1	4.003	4.548	0.55	15.78	0.03454	1.17
7	Static	1	4.436	4.641	0.21	5.58	0.03674	4.56
8	Curve left		4.383	4.770	0.39	11.79	0.03282	4.38
9	Curve left		4.821	4.957	0.14	3.03	0.04488	1.98
10	Curve left		4.970	5.064	0.09	2.67	0.03521	1.62
11	Curve left		4.336	4.529	0.19	6.72	0.02872	4.23
12	Curve right		4.276	4.491	0.22	6.18	0.03479	3.15
13	Curve right		4.357	4.503	0.15	6.00	0.02433	1.95
14	Curve right		4.359	4.672	0.31	6.54	0.04786	1.53
15	Curve right		4.505	4.809	0.30	7.05	0.04312	2.94
16	Dynamic	4	4.654	4.774	0.12	4.62	0.02597	3.72
17	Static	2	4.629	4.827	0.20	6.21	0.03188	2.13
18	Edge		4.657	4.868	0.21	5.73	0.03682	2.01

Table 5. GSR measurements for driver 3.

Peak	Trouble	Cod.	GSRmin (µSiemens)	GSRmax (µSiemens)	ΔGSR (µSiemens)	Δt (second)	m	Latency (second)
1	Edge		4.403	4.573	0.17	7.41	0.02294	2.37
2	Static	1	4.472	4.782	0.31	6.48	0.04784	0.45
3	Dynamic	8	4.616	4.819	0.20	6.18	0.03285	3.06
4	Static	1	4.483	4.700	0.22	6.12	0.03546	1.26
5	Static	2	4.580	4.717	0.14	2.76	0.04964	4.53
6	Dynamic	4	4.426	4.611	0.19	10.14	0.01824	1.53
7	Edge		3.848	4.705	0.86	17.43	0.04917	2.88
8	Static	1	4.570	4.806	0.24	10.23	0.02307	3.03
9	Static	1	4.514	4.623	0.11	4.65	0.02344	1.59
10	Curve right		4.335	4.513	0.18	6.42	0.02773	2.31
11	Curve left		4.236	4.943	0.71	10.86	0.06510	1.29
12	Curve right		4.855	5.270	0.41	13.26	0.03130	2.64
13	Static	2	5.201	5.259	0.06	2.46	0.02358	1.05
14	Edge		5.040	5.184	0.14	9.00	0.01600	2.88
15	Curve right		5.016	5.173	0.16	5.58	0.02814	3.27
16	Curve left		4.919	5.520	0.60	14.82	0.04055	6.99
17	Curve right		5.187	5.249	0.06	5.79	0.01071	0.45

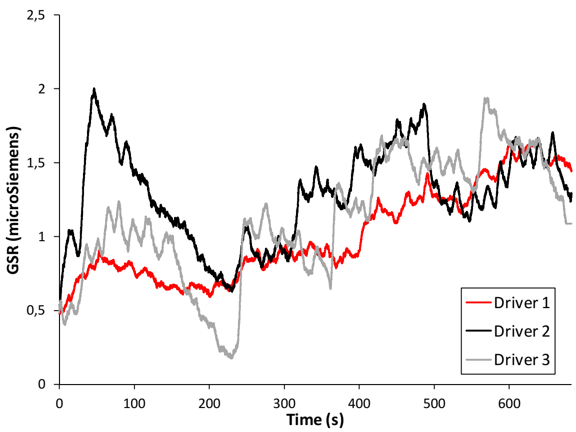

Fig. 2. GSR trend in the different tests.

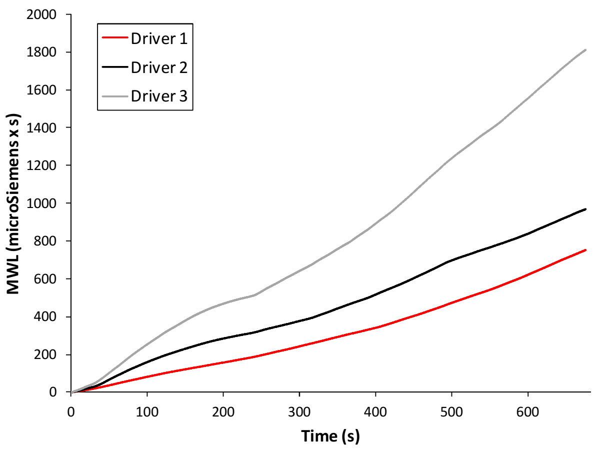

Fig. 3. MWL in the different tests.

In Tab. 3–5 there are the results of the test performed by each driver in terms of GSR. In detail, for each relevant peak, the authors listed the type of disturb and the related code, the minimum GSR (representative of the disturb perception), the maximum GSR (representative of the stress end), the difference between the max and min GSR (ΔGSR), the time gap between the max and min GSR (Δt), the angular coefficient m, and the latency.

4. Discussion

Identifying single peaks and referring them to the generating cause is significant to help the road administrators in taking proper decision for improving users' safety, by deleting or reducing eventual criticisms due to the road environment configuration. Unfortunately, there is a problem related to the stress accumulated by the driver since the beginning of the driving phase. This variable, deduced in this context by integrating the GSR curves, is logically growing while driving, but its trend (in particular, its angular coefficients) strictly depends on the driver's features, the encountered obstacles, the road type, and the section length. Then, in general, the results may appear not very meaningful. However, the test repetition by three different drivers shows interesting similarities in the MWL functions, evidencing a remarkable contribution of the road geometry (equivalent for all the users into certain boundaries), regardless of the position of the most evident peaks.

It is possible to evidence in Tab. 1 a very high percentage fixation value reserved to the parked vehicles (24.54%). In this case, the driver always doubts, at least at the beginning of the fixation, that the vehicle at the side of the road may move, becoming an actual safety disturb; then, he fixes his eyes to it for a considerable time. For this reason, although the rubbish bins represent a similar visual obstacle, they are seen for a shorter time (19.69%), because our brain already knows that they cannot suddenly move. It is interesting also to notice the very low percentage dedicated to the signage (7.32%): this is a proof that, at least for usual users, it does not condition the driving behavior.

A last notice regards the cockpit observation. In this case, the authors have reported only the effective fixation time, with no reference to a potential fixation time, since the cockpit is also in the driver's visual frame. Then, a percentage ratio would have no clear and effective meaning.

Tab. 2 underlines a very important aspect: the fixation times and the related percentage values depend on the disturb type and, above all, its moving direction. Due to their less predictable behavior and to the hazard of an eventual accident, the cyclists need high attention. This is higher when they are moving on the same direction of the user (58.90% versus 42.13% in the opposite direction), as the total time during which they are in the visual frame is longer and the driver has also to deal with the overtaking problem.

Considering other vehicles and motorcycles, this situation is further confirmed. Cars on the same direction are hard to overpass and determine a fixation equal to 36.66% (it is 2.46% in the opposite direction); similarly, motorcycles on the same direction show a higher value, 16.67% versus 3.36%. With cars and motorcycles, the users adopt similar strategies, because their speed are comparable in this road context.

Fig. 2 represents the GSR values measured for the three drivers. For sure, there are some affinities in the trends and these are probably due to the stresses induced by the road geometry, that represents a constant for all the drivers. The differences, instead, can be related to specific local solicitations, caused by several static or dynamic objects, randomly appeared during the tests. At this regard, the visual examination of the tapes acquired through the eye-tracker evidenced an almost perfect correspondence between the observation of an element representative of a new solicitation and the minimum of the GSR function.

In theory, after the external causes producing stress on the driver finished, the GSR function should show a decreasing trend to reach the physiological values of the user. An eventual new growing segment means that a new solicitation from the external environment appeared and it can be positioned in correspondence with the local minimum. It is not possible to obtain a perfect correspondence, because there is always a latency. This latency is, however, extremely variable as a function of the disturb (continuous, as a line of cars, or discontinuous, as a fix obstacle), the related importance for the driver, his psycho-physiological state.

The GSR cumulative function is a measure of the workload and is represented in Fig. 3. It should be observed that the trend is similar for the three drivers, but the gradient is different. Probably, this is due to differences in the resilience ability to absorb external stresses of the three drivers, despite the homogeneity in terms of age, experience, and driving capacity. Then, this graph might appear not very useful in the search for behavior similarities, but it is significant to underline specific critical scenarios in weaker users.

Tab. 3–5 are related to the GSR calculation and the derived measurements for the three drivers. However, they can be discussed together, avoiding distinctions among the tests, for the reasons discussed in the following. The last columns are the most interesting, because they list the time during which the disturb appeared (deduced through the fixation analysis), the GSR value when the disturb is actually perceived (minimum of GSR) and when the disturbing effect finished (maximum of GSR).

Since considering the absolute GSR value of a peak (min or max) could be irrelevant because of the influence of previous or following ones, the authors decided to consider the angular coefficient m, related to the segment linking the min and max of GSR. This coefficient provides further information regarding the driver's ability to get rid of the stress: if m is too high, the max happens very close to the min; on the contrary, when m is too low, the driver needs a longer time for the recovery. This can be indicative of the users' subjective performance or the solicitation intensity. If m is similar for all the peaks, then its value is strictly related to the driver's characteristics. If, on the contrary, it varies remarkably, it means that the disturbs have different intensities (as in these tests, in which m varies between 0.02 and 0.04).

In detail, in Tab. 3 there are 14 peaks, 7 due to the road geometry (6 curves and 1 tangent section) and 7 due to static (2 parked car) and dynamic (5, 3 of which are cyclists) objects. Regarding driver 2 (Tab. 4), in the 18 observation there are 11 peaks due to the road geometry (8 curves and 3 tangents) and 7 due to static (4, 3 of which are parked vehicles) and dynamic (3) disturbs. Finally, driver 3 (Tab. 5) noticed 17 peaks, 9 of which are caused by the road geometry (6 curves and 3 tangents) and 8 due static (6, 4 of which are parked cars) and dynamics (2) obstacles.

Consequently, the simple analysis of the visual behavior can not be sufficient to characterize the driving difficulties. It is true that the dynamic objects catch the driver's eye for a longer time than the static ones, but it seems that the MWL is mainly influenced by the static objects, such as the road geometry, the parked vehicles, and other fixed elements at the road side, because the visibility plays a relevant role in the GSR increase. At this regard, adding more columns in the tables would have allowed the authors to deepen the different observations. However, knowing the radius values, the deviation angles, obstacle sizes for buildings and walls, obstacle positions related to geometrical elements (tangents and curves) would have favoured a more accurate diagnosis, without any significant contribution to the WL quantification, which represents the object investigated in this research.

It appears, also, that ΔGSR, Δt, and m do not present values directly correlated to the related cause. This could depend on the high dependence of the ΔGSR and Δt on the previous and following peaks. From this point of view, the m value is more representative of the absolute GSR value, because, as previously said, it represents the driver's resilience against the external environment (depending on the age, experience, ability, etc.).

5. Conclusions

In this paper, the authors have investigated, more thoroughly than in the past, the role of the Mental Workload (MWL), relating it to specific elements of the road context. The aim is to evidence those causing the highest stresses to help the road administrators in the definition of specific activities for road improvement.

Using a particular instrumentation installed on an ordinary vehicle, the authors identified not only the MWL trend (in terms of GSR and its integral), but also the specific disturbances that caused that trend. This correlation, that should be further strengthened in the future with other tests, clarified the role of the critical geometrical issues of the road, of the marginal elements, and the traffic influence. These are all variables that, in different ways, can be significantly controlled by the road administrators, producing obvious improvements on the users' safety.

Since this study has analysed the existing situation on a real road, probably, the next step should be repeating the study in a simulated environment, to actually verify how proper corrections to the road context or the traffic flows can improve the driver's MWL.

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