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AN ANALYSIS OF THE EFFECT OF ROADWAY DESIGN ON DRIVER'S WORKLOAD

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Abstract. Driving behaviour is a direct consequence of the stimuli received from the road infrastructure, from the surrounding environment and from the atmosphere inside the vehicle. Almost all of these perceptions, which affect steering, are received through the drivers' eyes. For this reason, in this paper visual behaviour was examined in order to deduce new indexes connected to mental workload. To this aim, a consistent sample of drivers covered a rural road inside a vehicle, while their eye movements and driving activities were being recorded with suitable instruments. The quantification of some variables involved in the trials permitted the evaluation of visual behaviour and determination of a measure of mental workload, identifying also any situations where performance was compromised. Some reports between mental workload and road geometry, summarized in a few tables, could represent a further aid for road designers and managers**.**

Keywords: road safety, road design, visual behavior, mental workload, instrumented vehicle, image analysis.

1. Introduction

There are some definitions, proposed by the literature of recent years herein reported, but all of them have in common the uncertainty and the consequent difficulty of quantification, because of visual pathologies, skill, experience, risk inclination and level of attention.

One of the most famous definitions was reported in O'Donnell and Eggemeier (1986) which defined workload as that portion of the operator's limited capacity that is actually required to perform a particular task. Workload measurement is the specification of the amount of capacity used.

Others authors (Meijman, O'Hanlon 1984; Wickens 2002; Zijlstra, Mulder 1989), in a rather simple way described mental workload as the difference between the cognitive demands of a particular task and the driver's attention resources.

Workload is strongly influenced by human nature and not just by the task. It is, therefore, a mistake to associate task demands and the effect of these demands on the driver, using the same term. Instead, the goal, achieved by means of task performance, which determines the demand and its effect on the driver, is really the workload (De Waard 1996).

De Waard (1996) produced a list of factors that affect driver's workload, referring to the driver's state of being (monotony, fatigue, sedative drugs and alcohol), trait (experience, age and strategy) and environmental factors (road environment and traffic demands, vehicle ergonomics, automation and feedback).

In a well-known study, a list of many important parameters useful for properly characterizing the mental workload were introduced by Eggemeier *et al.* (1991) and then perfected by other authors. They are sensitivity, diagnosticity, selectivity, intrusiveness, reliability, implementation requirements and subject acceptability.

As to achieving a correct quantification of methodology, the evaluation of mental workload fell into these 3 categories: a) performance measures – any increase in task difficulty will result in an increase in demand as well as a decrease in performance; b) subjective measures based on the perceived effort by the drivers and c) physiological measures believed to be proportional to mental workload.

Among physiological measures, there are eye movements, ie the central argument of this paper. To this aim, visual-search strategy, or the selective attention to relevant visual stimuli, has been shown as indicative of information needs (Hughes, Cole 1988), as also demonstrated by O'Donnell and Eggemeier (1986) who report an increase in workload proportionally with an increase in fixation time.

In accordance with the previous researches, it was ascertained that steering and field of view dimension variability may indicate processing demands. The functional field of view is an area around the central fixation point, from which information is actively processed during the performance of a visual task.

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Rubio *et al.* (2004) evaluated some psychometric properties, a few being intrusiveness, sensitivity, diagnosticity and validity, already illustrated by Eggemeier *et al.* (1991) of 3 subjective workload assessment methods: the NASA Task Load Index (*NASA TLX*), the Subjective Workload Assessment Technique (*SWAT*) and the Workload Profile (*WP*). Finally, other authors (Green 2004; Guhe *et al.* 2005; Patten *et al.* 2006; Wickens 2002) examined the role of the unstable and uncertain nature of human factors.

The results obtained until now, however, are not well fit for improving the road design quality.

This happens due to: the proposed indexes being too general, many times the experimentations being carried out (inside laboratories) instead of in the "real world", and the lack of any relationship between measured workload and road variables. This step is required to reach a "workload-based design" for new or existing roads (Brauers *et al.* 2008).

This paper, in an attempt to overcome these difficulties, pursues the previous goals.

2. Methods

The conviction that drivers are heavily influenced by a series of factors that often increase mental workload, such as interaction with other vehicles, light conditions, geometric peculiarities, vertical and horizontal road signs and alignment characteristics, was widespread in the scientific community for many years (Antov *et al.* 2007).

To monitor these new variables, by means of an instrumented vehicle, some video-tape recordings of road contexts and eye movements were made, while sensors tracked variables such as distance covered, speed, longitudinal acceleration and use of the accelerator and foot-brake pedals. A portable GPS was also used to track the driver's position on the road.

The results were then further filtered and analyzed, in order to extrapolate key parameters and correlate them appropriately.

2.1. Selection of drivers

Before beginning road trials, 24 potential drivers who had completed a detailed driving style questionnaire (French *et al.* 1993), were selected.

All the questionnaires were analysed and, in order to max homogeneity within the group, some drivers were excluded. During on-road trials, certain situations beyond our control involving traffic, weather and light conditions also proved a threat to test homogeneity.

It was for the above reasons that the study was restricted to 18 participants who shared very similar driving behaviours rather than using the more disparate 24-strong sample originally contemplated.

2.2. The trial vehicle

Equipment for tracking head/eye movements, road environment and main variables regarding the dynamic vehicle (acceleration, speed etc.) was installed on a Lancia Delta 1.6.

The equipment included 3 micro-cameras, concealed within the car's interior to avoid obtrusiveness. The 1^{st} of these provided a reasonably accurate picture of the driver's view ahead, the 2^{nd} reproduced the view through the rear-view mirror and the 3^{rd} recorded head and eye movements in greater detail. A special programme was written in order to coordinate this instrumentation, since highly specific requirements of the research made it impossible to use any of the more standard commercial applications (Fig. 1).

Fig. 1. Graphic interface of the 3 video cameras and the telemetry in real time

2.3. Road analysed

The trials took place on a rural road over a distance of about 7.7 km with a uniform track in terms of cross-section and construction.

2.4. Subsequent calculations

The recordings, by means of image analysis and processing, allowed the recognition of head/eye movements and certain driver postures associated with specific manoeuvres. It was necessary to setup an ad-hoc software. To obtain further information about theoretical bases, all the necessary references were included in the bibliography (Bosurgi *et al.* 2004a; 2004b; 2005; 2007; Gonzales, Woods 2007).

For drivers with no eye conditions linked to strabismus, movements of the right and left eye were practically identical. Moreover, the *Y* coordinate provided no important information since movement of the head/eye system inside the vehicle occurs mainly along the *X* abscissa. Therefore, it is sufficient to only analyse coordinate *X* for the right eye, which simplifies the procedure considerably.

The *X* and *Y* coordinates of both eyes can, however, be used for automatic recognition of the driver's head position. The inclination of the line joining the pupil centroids, together with other constraints determined by facial morphology, makes it easy to establish head inclination and, consequently, to estimate direction of gaze.

The raw data for movements of the head/eye system were compared with road geometry, environmental context and traffic conditions in order to pinpoint any information overload (Zariņš 2006).

In particular, some functions were characterised:

– The context information (*CI*) function, obtained by means of filtering the average eye movements' data of the sample, and a subsequent regression with a Fourier function of the 8th order. This function represents only the movements of the head/eye system gazed at research-necessary information, in free-flow condition, i.e. without traffic.

– Max, min and inflexion points of *CI* function. These points, in relationship to road geometry, influencing drivers' visual strategy in free-flow condition, permitted the evaluation of the accuracy of the feed-forward and feedback mechanisms introduced by Donges (1978) and Land (1992, 2006). In particular, at the inflexion point, a driver began to interpret the bend, looking at the tangent point of the curve. In the max (or min) point, this interpretation was finished. The distance covered from the inflexion point and the max (or min) point, is in this paper called the length of interpretation (*LOI*). The distance from the inflexion point and the start of the curve is indicated as available length (*AL*). Finally, the distance from max (or min) point and the centre of the bend is called the margin of safety (*MOS*). The same consideration could be carried out with time, introducing only the speed of drivers (Fig. 2).

– The visual load index (*VLI*), described also in previous papers (Bosurgi *et al.* 2004b, 2005, 2007; Gonzales, Woods 2007). It is a sudden deviation from the trajectory of the driver's gaze, in order to sample visual information of interest, both inside and outside the standard field of visual activity. It is a useful parameter to consider traffic influence on driver visual strategy and it is measured as the difference from *CI* function (eye movements of the sample) and eye movements of a specific driver, due to an unexpected object or situation. It is therefore an index of environmental complexity in terms of road geometry, traffic flow and visibility. If this difference was less than 20 pixels, the *VLI* was assumed to be of no value. In fact, little difference could be due to noise inside the functions, caused by unevenness of the pavement, vibrations and so on.

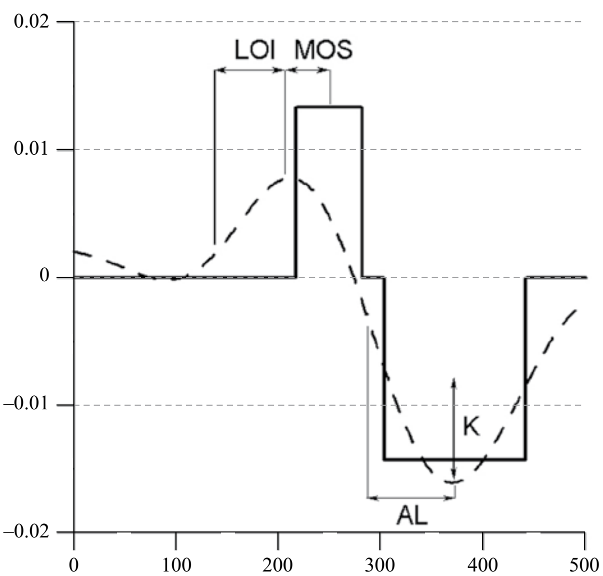

Fig. 2. Relationship between *LOI*, *MOS*, *AL* and *K*

– The visual energy (*E*) given by the quantification of the integral of the above-mentioned *CI* function, since it represents the energy expended by the driver in interpreting the road. This *E* can be measured for a single geometric element, such as a curve, or for a whole section of roadway, in order to assign a specific or general level of difficulty.

Finally, the principal results were collected into Tables 1 and 2. In the Table 1 the variables about the average data of the sample were reported, sorted by reference to the bends of the section analysed. The aim was to verify the relationship between the visual load and the singular elements of the road.

Successively, in the Table 2, data from a specific driver were reported in order to evaluate, if a particular visual load caused by the traffic determined a decrease of the performance.

Specifically, the length of said *MOS* was evaluated as being the difference between the last progressive with presence of *VLI* and the max or min point of the CI function. If it was still positive, then driver could correctly interpret the road alignment, otherwise the performance was compromised. This last procedure was be repeated for all the drivers.

The most complex aspect is the judgment of the so-called overload and underload thresholds, that is, those indicative of situations of excessive taskload or, on the contrary, of insufficient attention while driving. The difficulty of the positioning of the aforementioned thresholds has already been discussed, in how direct measures of workload are very subjective, and therefore lend themselves poorly to interpretation of a general nature. In that respect, the consideration that rises from the most recent studies is that the threshold should regard performance measures and not those of workload. As, on the other hand, noted in literature, the workload and performance variables are related to each other in an inversely proportional manner, in the sense that at the increase of the 1st, there is a decay of the 2nd. It is believed, rather, that the performance gaps depict, with a certain amount of precision, the positioning of the above-mentioned thresholds.

In the field of road engineering, the choice of opportune performance functions could examine the vehicle speed, the frequency of checking the instrumentation and rear-view mirrors etc.

In this work, it was chosen instead to calculate the speed differences (ΔV) regarding the possible overload subsistence within the single geometric element (only for $\Delta V > 10$ km/h) and "balancing" the vehicle on the lane's axis line along a straight stretch for that concerning underload (only for $\Delta x > 0.50$ m).

Actually, elevated accelerations and decelerations always lead to an information overload, and, in any case, a more burdensome driving task. On the contrary, a monotonous drive and a state of boredom, generally express

Table 1. Relationship among geometrical and visual variables

Curve No.	Radius R, m	Visual energy E, pixel	Length of interpretation LOI, pixel	Margin of safety MOS, pixel	Available length AL, pixel
1	75	0.39	50.00	37.00	55.00
2	−70	0.80	78.00	2.50	12.00
3	180	0.20	84.00	48.50	83.00
4	160	0.13	56.00	18.00	39.00
5	−160	0.34	84.00	−10.00	44.00
6	−400	0.24	0.00	0.00	0.00
7	130	0.39	156.00	−49.00	156.00
8	1350	0.21	0.00	0.00	0.00

Note: the value of the radius could permit to link the visual behaviour to the road standard

Table 2. Relationship among geometrical and workload variables

Curve No.	Radius R, m	Visual load index VLI, pixel	Max context information CI_{max}, pixel	Safety margin ΔMOS, pixel	Highlighting index ΔV, km/h
1	75	280.00	212.00	−68.00	8.49
2	−70	454.00	370.00	−84.00	2.51
3	180	561.00	604.00	43.00	1.93
4	160	684.00	724.00	40.00	7.33
5	−160	0.00	874.00	–	3.28
6	−400	1087.00	0.00	–	6.94
7	130	0.00	1207.00	–	2.12
8	1350	1294.00	0.00	–	0.19

Note: ΔV could be assumed as a measure of overload

themselves with trajectories that diverge from the lane's axis with periodic progress. It was chosen to calculate such a measure only on straight stretches of a certain length, because in a curve the driver always tends to drive along a line that minimises the distance covered or the centrifuge acceleration sustained. For completeness, and for the same reason, short straight stretches, as well as those initial and final, would be rejected, in that the effects of the already assumed position (or which will be assumed) on the curve are felt, and the vehicle needs a certain amount of space to reposition itself correctly along the axis line

3. Results

The experimentation was performed in two main phases. The 1st one was characterised by on-road trials, undertaken at the same time and under the same traffic conditions for all participants. The 2nd phase related to post-processing the telemetric data (speed, longitudinal and transversal acceleration, vehicle position and, therefore, trajectory) and, more importantly, the examination of the relationship between these measurements and the driver's visual behaviour. This was achieved through a software written in the Matlab® language.

Eye movements were represented in a Cartesian diagram with units of measurement expressed in pixels. To best represent many variables with the same graphic, the coordinates of the head/eye movements were transformed by means of this operation:

$$\text{new coordinate} = \frac{\text{old coordinate} - 150}{2500}.$$

The raw data of eye movements were successively filtered, considering the different drivers' tall or "noise" as being pavement roughness, and deleting some singular visual behaviour caused by particular situation such as pedestrians, cyclists, crossing traffic etc.

A function was plotted based on the average values of all the drivers' eye movements and, in particular, a regression of these data was performed by means of a Fourier function, here called context information (CI) having the following characteristics:

$$y = a_0 + \sum_{i=1}^{n} a_i \times \cos(n \times \omega \times x) + b_i \times \sin(n \times \omega \times x),$$

where a_0 models any constant component in the signal, and is associated with the $i = 0$ cosine term; Δ is the fundamental frequency of the signal in hertz and n - the number of terms (harmonics) in the series.

The result of this operation produced the function called CI with a very good correlation (residual sum of squares $SSE = 9.022$; correlation coefficient $R^2 = 0.9316$; correlation coefficient adjusted $R^2 = 0.9308$; estimated root mean-squared $RMSE = 0.07921$).

The presence of a sudden visual request, indicated through the VLI, was quantified as the difference between the ordinates of the *CI* function, representative of the average visual behaviour of the sample, and the head/eye movements (*EM*) function, relative to the examined driver's visual behaviour (Fig. 3).

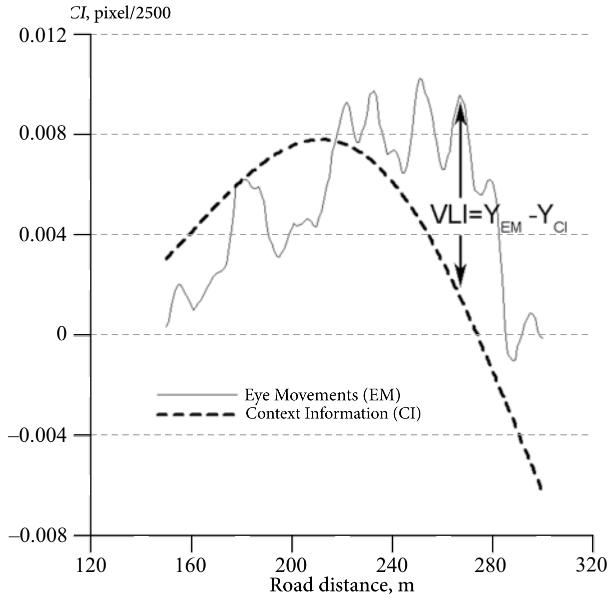

Fig. 3. Determination of *VLI* as the difference between the *EM* and *CI*

If this difference was significant (more than 20 pixel), the driver had moved his head and eyes to control some object of special interest. This situation (presence of *VLI*) creates a problem that has been highlighted on the graphics as a little bold circle, placed in correspondence with the right road abscissa.

In the next step, through determining of the integral of the *CI* function, the *E* was extracted. This is representative of that aliquot of mental workload caused by road geometry.

This is not, however, the only parameter indicative of workload being borne; it is also indispensable to establish at what distance (both physical and temporal) from the start of the curve the driver began his assessment of it. Equally fundamental is a knowledge of the point at which the driver's attentions ceased to be absorbed by one section or characteristic of the road, and were directed towards the next. All of these measurements determine the difficulty or ease with which the acquisition of all the information necessary to interpret a road section is achieved.

Then, the prime and the second derivatives of the *CI* function were calculated in order to determine the max, min and inflexion points, and to verify the visual behaviour with respect to road geometry (*RG*). For this purpose, the distance *LOI*, *AL* and *MOS*, based on the relationship between *CI* and *RG* functions, were reported in Table 1 and, therefore, represent the behaviour of the drivers' sample. The *MOS* variable is, maybe, the most important for characterizing the driver's performance subjected only to the road geometry.

Finally, to quantify the total mental workload, it was also necessary to add the impulsive contribution of *VLI*, due to an information-rich environment in a short time.

Figs 4 and 5 explain then, the *E* function increasing with the road distance, in abscissa, and that, in a particular section of the road, some peaks in correspondence with the *VLI* are presented.

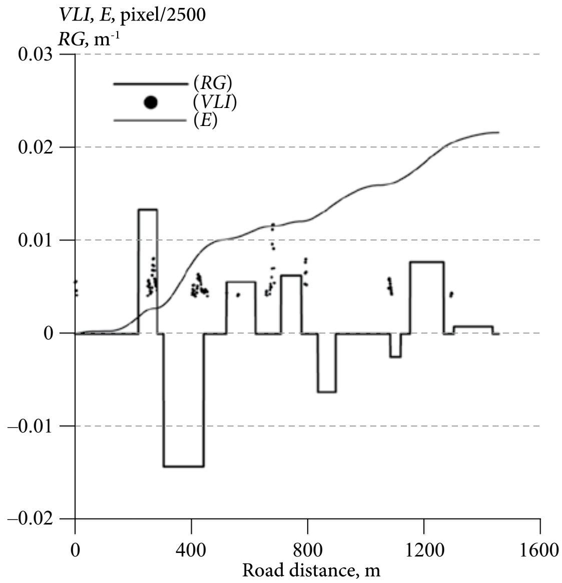

Fig. 4. Relationship between *E* representative of the load caused by *RG*

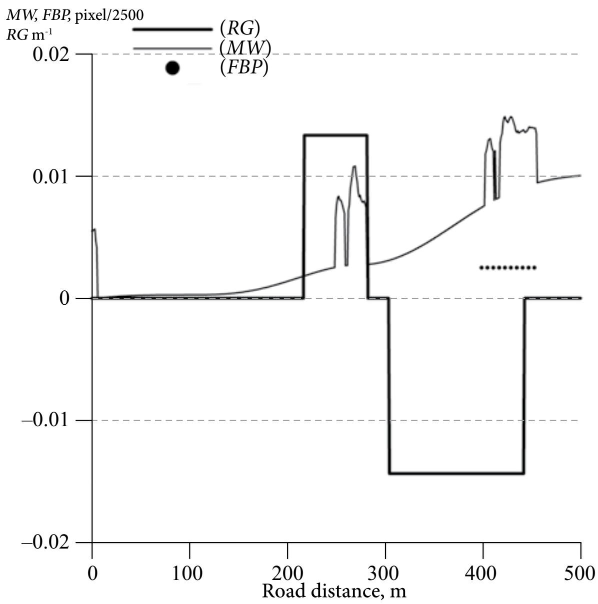

Fig. 5. Relationship between *MW*, deduced from the sum of *E* and *VLI*; in the section from 400 to 460 m there is an activity on the foot/break pedal represents an overload situation

It was noted during the trials that the overload induced by *VLI* sometimes caused an abrupt decrease of the speed *V*. In fact, when confronted by a potentially dangerous presence such as other vehicles or unusual geometric peculiarities, drivers were required to process additional information, the complexity of which exceeded their own analytical ability. This resulted in a reduction of vehicle speed in order to extend the time available for decision-making and this decline of the performance could be a clear symptom of overload, even if there are no statistical proof of this.

However, it would be more interesting to analyse the results that were briefly reported in the Figs 6–8 and in the Tables 1 and 2.

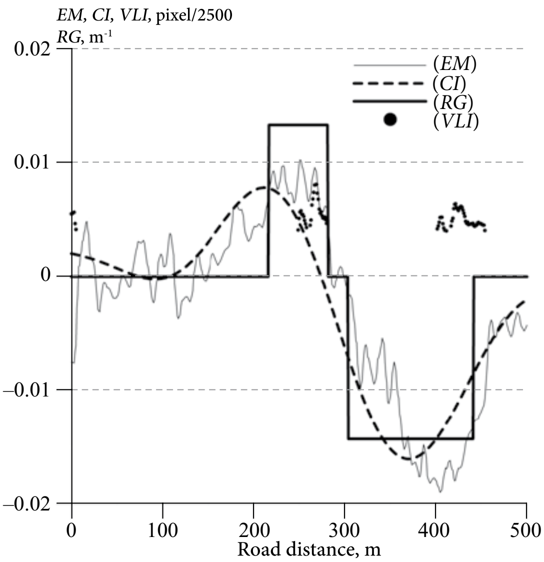

Fig. 6. Relationship between *CI* function of the sample and *EM* and *VLI* for a specific driver (the ordinates in pixel of *EM*, *CI* and *VLI* were scaled for 2500 to represent also the curvature diagram (*RG*) in the same graphic; the data concern the road distance from 0 to 500 m)

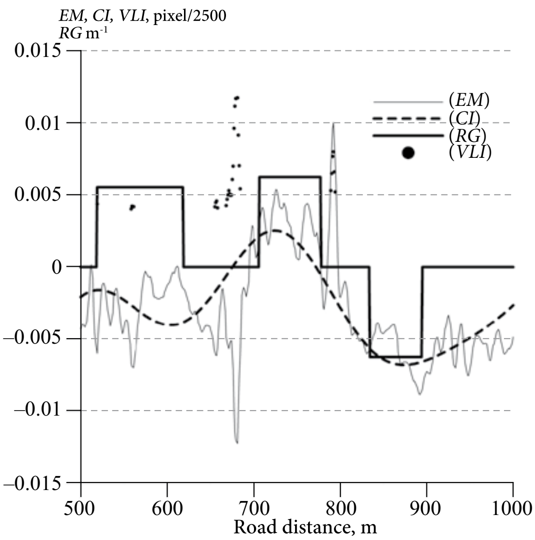

Fig. 7. Relationship between *CI* function of the sample and *EM* and *VLI* for a specific driver (the data concern the road distance from 500 to 1000 m)

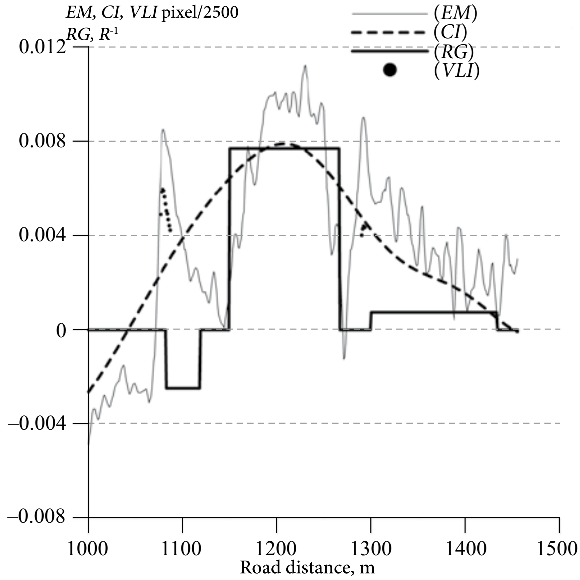

Fig. 8. Relationship between *CI* function of the sample and *EM* and *VLI* for a specific driver (the data concern the road distance from 1000 to 1500 m)

For very large radii ($R > 160$ m), drivers used only the feed-forward predictive mechanism, as they did not need to seek further information. Interpretation of the curve through the observation of the inside road edge began on the tangent at a distance directly proportional to vehicle speed, and once beyond the initial section of the curve, drivers would focus on processing information relative to subsequent elements (distance *MOS* always positive for $R > 160$ m).

In situations in which very little time was taken away from interpretation of road context (for example, to quickly glance at the rear-view mirror), drivers did not modify their behaviours, whereas they would decelerate quite dramatically when they took longer to analyse road context.

Indeed, for small radii, or when one vehicle overtook another travelling at similar speed, or in conditions of less than optimal visibility, the mechanism was different. Drivers were far more visually alert, and for a longer period of time, with the result that the head/eye system showing much more marked deviations from the straight line in which they were travelling (Fig. 6 – road distances 220 m and 370 m; Fig. 7 – road distance 870 m; Fig. 8 – road distance 1200 m). A major deviation from standard head/eye position indicates the driver to be examining a nearby point at one side of his vehicle, that he deems this necessary to his driving safety.

In line with research described by Land (1992; 2006), this study established that drivers tended to direct their gaze towards the tangent or vanishing point, which thus serves as a guiding device, even in the absence of traffic. Nevertheless, these experiments also demonstrated that most of the driver's attention is focused on other vehicles, when these are present. Both during negotiation of a curve and on the straight, the presence of other vehicles determines quite a different visual behaviour from that deployed when driving in isolation. Of course, this can result in an increased *VLI* (Fig. 7 – road distances 680 and 780 m; Fig. 8 – road distance 1070 m).

The persistence of positive *VLI* values over a limited section of road (Fig. 6 – road distances 250–280 and 400–460 m) indicated also that a driver identified a possible obstacle in his path and needed time to interpret it in order to avoid compromising his own driving safety. Such scenarios occurred, for example, upon sighting a vehicle waiting to cross an intersection, or when passing another vehicle at a similar speed (Fig. 7 – road distance 680 m). Conversely, isolated *VLI* values are indicative of periodic information sampling through the observation of road signs or rear-view mirrors (Fig. 7 – road distance 520 m).

Slight differences in absolute values, though not in trends, were recorded for speed and trajectory, the variability of which was also influenced by the carriageway width.

On the contrary, homogeneous behaviours were observed in a number of very frequent driving scenarios. For example, when proceeding at low enough speeds, drivers would periodically seek additional information using the rear-view mirror and on-board instrumentation. Obviously, the ability to manage information derived from a number of sources is essentially a function of driving skill and, therefore, of the category of driver into which the individual road user falls.

The *CI* function has a generally valid relationship with road geometry. Curve No. 2, for example, with $R = 70$ m, has a very small *MOS* because the driver simply did not have the space necessary (small *AL*) for advanced interpretation of the curvilinear element and was, therefore, forced to perform this activity over a shorter distance and space of time. In this case, the very limited length of the tangent of road preceding the curve under examination made a decisive difference.

It could be said that the *LOI*, *MOS* and *AL* variables are highly dependent on the geometry of the elements preceding them and that it is, therefore, important for radii not to be too dissimilar from one other. In fact, if the driver does not have sufficient time to interpret a new curve, he will deal with it in much the same way as he dealt with the previous one. This observation casts further doubt on the wisdom of the current trend for designing roadways with continuous curves, i.e. with no tangent between one curve and the next.

Table 2 refers to the single driver and not to the sample. Such a condition determines that, ever-referring to single curves, it is possible to quantitatively specify the *VLI*, or the second term which leads to the quantification of the global mental workload.

For this purpose, in the relative column the maximum value of the *VLI* is not reported, but, rather, the final point of the spatial interval, in which this form of visual overload took place. The data, compared with the continuous roadway which has the max *CI* function (CI_{max}), provides an index representative of the variation of the safety margin, named here ΔMOS that, in its time, returns an indication as to the spatial and temporal interval which the driver uses to acknowledge information as to the element being confronted, after the cause producing the VLI has stopped. This distance, in a few cases, had negative results, as can be seen in the first two row of the Table 2, where the driver underwent a *VLI* of notable duration, enough to bring on an evident speed variation.

The ΔV is is assumed in this research as the index for highlighting the surpassing of the overload threshold. The data emphasize that in the 1st, 4th and 6th curve, there are speed differences of a certain relevance, without, however, it being a symptom of excessive overload beyond the driving capacity limit (here assumed $\Delta V >$ 10 km/h). It follows that the overload threshold was not exceeded, in that the performance decay, connected to speed variation, is not excessively pronounced.

Such a variable cannot be used, however, for the identification of a state of underload, in that the speed constancy does not always lead to a state of boredom or potential carelessness of the driver.

As to the surpassing of the other threshold, that of underload, with the aid of Image Analysis techniques, the transversal position of the vehicle, with respect to the lane axis along a straight stretch, was calculated without noticing driving behaviours tied to boredom or carelessness. The examination of Fig. 9 demonstrates that the driver follows in a sufficiently faithful manner the lane's axis line, detaching himself only in proximity to the curves for reasons already illustrated previously. In a completely straight stretch, a deviation of nearly 16–17 cm from the axis with fluctuations of a few centimetres with respect to the followed track, leads to a situation that can be considered as absolutely normal.

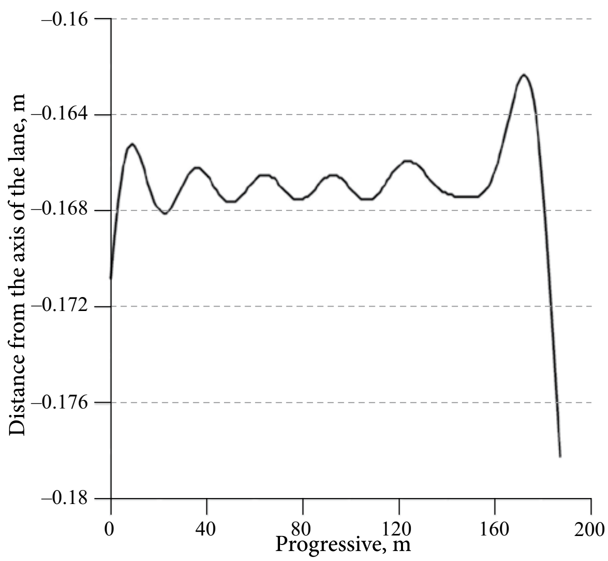

Fig. 9. Position of the vehicle respect to the centre line of the lane to verify the presence of underload

4. Conclusions

With this research is proposed a measure of physiological workload by means of drivers' eye movements. The trials performed made it possible to confirm some results already known to the literature, helping some controversial issues, such as the practice use of results in road safety and identification of the thresholds for overload and underload.

It was demonstrated that the estimated workload during the test depends on the requested capability during the activity of driving and on the environmental complexity.

Fig. 5 shows that the Mental Workload (*MW*) function has 2 peaks caused by a complex geometric situation (two consecutive bends of opposite sign) and acquired by the user even with the aid of the brakes which made it possible to have more time available.

The dependence of *MW* on the context is fully consistent with the arguments advanced by O'Donnell and Eggemeier (1991) and De Waard (1996), although relative to the latter was not possible to verify the relationship with other variables such as the use of drugs, alcohol etc., for obvious safety reasons.

Another important conclusion is that none of the methods briefly enunciated in the Introduction section, alone are sufficient to determine mental workload. It is necessary to verify the same activities with another measure, possibly of a different class. For example, this application could be completed with a subjective model, as *NASA TLX* or other self-report measures, but only to illustrate the complete methodology, this research was proposed as stand-alone.

It was emphasize another relevant aspect of this work: the trial was conducted over a public road. This resulted in an impact on the sample of drivers much more realistic than any test with a simulator, also because the instrumentation used to record the most important variables is absolutely not invasive.

As for the usefulness of this work workload measure could be an aid to the design of new or existing roads.

The validity of the methodology on existing roads has been proven through testing performed, with the highlight of the significant workload increases in correlation with road alignments difficult to interpret.

On new roads, it is necessary to develop a first step on the correlation between visual behaviour while driving and variables within the environmental context, such as geometry, distances of visibility, interaction with drivers, conditions of light etc.

This correlation, necessarily conducted on the basis of trials already performed, will lead to a previsional analysis carried out by means of fuzzy logic and Monte Carlo simulation. These instruments are being studied and refined by the author.

Moreover, the next steps will cover in greater detail the position of the redlines. Indeed, the findings deduced in this experiment must necessarily be enriched by additional indexes that allow a relationship between the excess of such limits and the probability of erroneous action by the drivers.

Finally, the next trials should be supplemented with other classes of users, such as the elderly, in order to deduce suitable safety coefficients.

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