Drivers' perception of simulated loss of adherence in bends

Thomas Denoual, Franck Mars, Jean-François Petiot, Gilles Reymond, Andras Kemeny

IRCCyN (Institut de Recherche en Communications et Cybernétique de Nantes)

Renault, Technical Center for Simulation

1 avenue du golf – 78288 Guyancourt, France

thomas.denoual@renault.com, franck.mars@irccyn.ec-nantes.fr, jean-francois.petiot@irccyn.ec-nantes.fr, Gilles.reymond@renault.com, andras.kemeny@renault.com

Abstract - *Loss of adherence (LOA) in bends, due to excessive speed or alteration of road grip, can lead to loss of vehicle control, which is a cause for many accidents. This paper presents preliminary results of an experiment studying how drivers perceive and react to vehicle skidding in a fixed-base simulator. Situations of LOA inducing a significant modification on the vehicle trajectory without involving a brutal loss of control or a road departure were chosen. The intensity and the duration of the LOA were manipulated. Naive participants repeated short drives on a track made of a straight road followed by a bend and were asked to answer a questionnaire after each track. To describe the LOA, two types of indicators were used: objective indicators of steering control and subjective indicators based on verbal descriptors scaled after each track. Preliminary results showed that drivers were able to discriminate the different conditions of LOA. The intensity of the perturbation was well perceived, with minimal influence of duration and not apparent relation to the magnitude of the steering correction. By contrast, a distortion of subjective time was observed when the duration of the LOA was assessed. Further analyses will be conducted to determine to what extent objective and subjective indicators were related. This study is the first step to develop an evaluation method that could be applied to the evaluation of ESC system intervention in high performance simulators.*

Résumé - *Les pertes d'adhérence (PA) en virage, dues à une vitesse excessive ou une altération de la tenue de route, peuvent entraîner des pertes de contrôle qui sont la cause de nombreux accidents. Cet article présente les premiers résultats d'une expérience qui étudie comment les conducteurs perçoivent et réagissent face à un dérapage du véhicule. Les situations de PA choisies induisent une modification perceptible de la trajectoire du véhicule sans provoquer une brutale perte de contrôle ou une sortie de route. L'intensité et la durée de la PA ont été manipulées. Des participants naïfs ont répété plusieurs conduites sur parcours simple composé d'une route droite suivie d'un virage.*

Pour décrire les PA, deux types d'indicateurs ont été utilisés: des indicateurs objectifs du contrôle de la trajectoire et des indicateurs subjectifs basés sur des descripteurs verbaux cotés après chaque passage. Les premiers résultats ont montré que les conducteurs sont capables de distinguer les différentes conditions de PA. L'intensité de la perturbation a bien été perçue, avec une influence minime de la durée, sans relation apparente avec l'amplitude de la correction au volant. En revanche, une distorsion du temps perçu a été observée. Des analyses plus poussées seront menées pour déterminer dans quelle mesure les indicateurs objectifs et subjectifs sont liés. Cette étude est une première étape dans le but de développer une méthode d'évaluation qui pourrait être appliquée à l'évaluation des interventions d'un ESP dans un simulateur haute performance.

Introduction

Loss of adherence (LOA) can lead to loss of vehicle control, which causes many accidents. Electronic stability control (ESC) can limit the consequences by correcting the vehicle trajectory according to the driver's intentions and dynamics of lateral acceleration, yaw speed or drift of the vehicle (Liebemann, 2004; Erke, 2008). The calibration and validation processes are time consuming and require physical prototypes and experts drivers on specific grounds, especially for very low adherence situations. Consequently, driving simulators are being used to study LOA episodes and ESC performance (Papelis *et al.,* 2010). Driving simulators are useful tools in vehicle design and perception studies. They allow to safely explore critical situations with naive drivers without environmental bias (Kemeny, 2009). The present study is the first step of a research program aiming at understanding how drivers perceive and react to trajectory perturbations and, further on, to the intervention of an ESC system. This could be useful for the engineering specifications of ESC using driving simulators and to evaluate how actual drivers perceive different system configurations.

During LOA episodes inducing sudden changes in the vehicle trajectory, the driver must perform an appropriate steering response to maintain the vehicle into the lane and avoid road departure. Numerous sensorimotor models have been proposed to explain how drivers use visual, vestibular and haptic information to steer a vehicle in normal conditions (Donges 1978, Reymond *et al*., 2001, Toffin *et al*., 2007). However, little is known about sensory cues that are used by the driver to detect LOA episodes and how steering responses are carried out. Besides, hierarchical model of cognitive control applied to driving postulate that steering mainly relies on sensorimotor loops which operate below the level of consciousness (Hollnagel 2004, Michon 1985). Typically, emergence to consciousness arises when external disturbances occur (Hoc and Amalberti 2007). Assessing at the same time steering responses to LOA and the associated subjective experience may be a way to investigate how sensorimotor cues determine the conscious evaluation of driving incidents.

This paper presents a driving simulator experiment in which episodes of LOA were triggered to produce significant modification of the vehicle trajectory without loss of control and road departure. Intensity and duration of the LOA were manipulated. The first objective was to develop an evaluation method to describe LOA episodes by means of subjective indicators using a non-structured-scaled questionnaire (Strigler, 1998). Objective indicators of the vehicle's dynamic and driver behaviour were also analysed. Another objective was to determine to what extent objective and subjective indicators were related (Mellert, 2007).

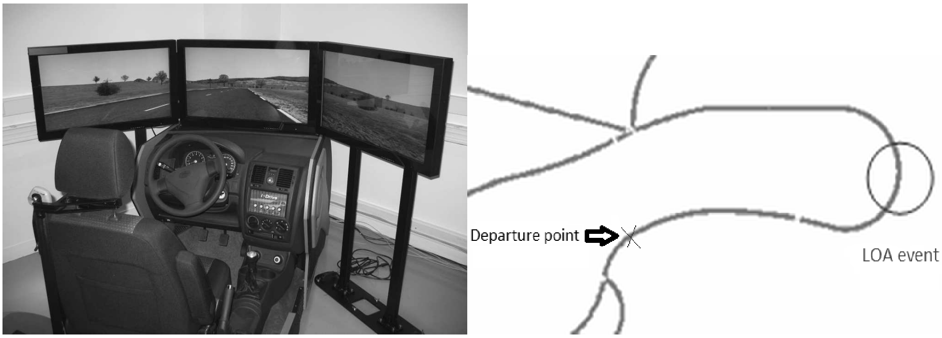
Method

Participants

Four female and sixteen male drivers between 20 and 24 years old (mean age of 21.4) participated in the experiment. They had driving licence for 3.4 years on average and drove between 1000 and 25000 km per year (mean = 6325). All of them had normal or corrected-to-normal vision. Fourteen participants declared that they had already faced to a loss of adherence situation on the road, two of them during a specific driving lesson. Two participants had already used a simulator.

Apparatus

The experiment was conducted on a fixed-base simulator at IRCCyN laboratory (Nantes, France). It consists of a compact size passenger car with actual instrument panel, clutch, brake and accelerator pedals, handbrake, ignition key and an adjustable seat with seat-belt. Transmission is done by an automatic gear box. Vibrators are installed at the bottom of driver seat and upper position of the steering column to render engine noise and vibrations. Active steering force feedback is rendered by a TRW steering wheel. The audio system renders the audio environment for an interactive vehicle. It contains an amplifier, 4 speakers and sub woofer.



(a) **(b)**

Figure 1. (a) IRCCyN driving simulator. (b) Layout of the country track

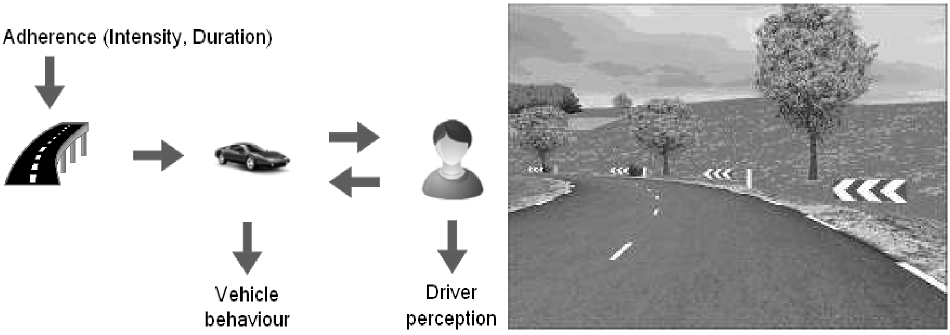
The SCANeR©II[2] software package was used with CALLAS© dynamic vehicle model (Lechner *et al*., 1997).

[2] http://www.scanersimulation.com/

The visual environment was displayed on three 32 inch LCD monitors with a resolution of 1280 x 720 each, one in front of the driver and two laterals inclined of 45° from the front one, viewed from a distance of about 1 meter and covering 115° of visual angle (Fig. 1a). The graphics database reproduced an open countryside environment. The experiment was performed on a short part of the environment which consisted in a straight line followed by a bend (total distance: 700 m, mean radius in the bend: 111 m) without traffic (Figure 1b).

A simple generic speed regulator was used, consisting of a PID corrector with a nominal speed of 75 km/h, using the automatic gearbox mode in order to reject inter subject velocity bias. This condition also allowed the subject to be only focused on the steering task.

Two type of LOA were simulated in the bend by modifying the adherence under the wheels when the vehicle reached a defined point. The intensity (adherence coefficient) and duration of the simulated LOA in the bend were manipulated as independent variables (IV). An adherence coefficient decrease corresponds to an increase of the intensity of LOA. These values of intensity and duration values were chosen to induce perceptible but controllable LOA. LOA was simulated either on the four wheels (LOA1) or on the rear wheels (LOA2). The LOA1 situation induced a skidding to the outside of the bend comparable to an actual situation of driving on a patch of black ice, a puddle or a pool of oil depending on the independent variables values. The LOA2 induced situations similar to over-steering. The results of the LOA2 are not presented in this paper. After the LOA, coefficient of adherence was set again to 1. The environment was not giving clues about a potential LOA (snow, rain or mark on the road) (Fig. 2b).



(a) **(b)**

Figure 2. (a) Input and output data. (b) Visual environment in the bend

Procedure

The subjects settled themselves in the simulator while preliminary instructions were given. In particular, they were asked to keep their lane without cutting the bend even if there was no oncoming traffic. Then, they were invited to start the simulator and drive a 10 minutes session for training. Next, they drove around the test bend with automatic gearbox and speed regulator on with the repeated instruction to stay in their lane and focus on the trajectory. Four trials without any LOA were performed in order to familiarize the subjects with the bend.

For each type of LOA, a control condition (no LOA) was inserted in the experimental design. The order of presentation of LOA1 and LOA2 was counterbalanced across the subjects. The same Williams Latin Squares design (Williams, 1949) was adopted for each type of LOA to avoid rank and carry-over effects. 20 trials divided into two sequences of each type of LOA preceded by 4 preliminaries trials representing mild and strong LOA episodes were performed. Those 8 preliminaries trials were conducted in order to familiarize the participants to the range of steering perturbations they would encounter during the experiment. They were not analyzed. The two types of LOA induced very different modifications in the vehicle behaviour and situation's perception. Therefore we have chosen this block design to avoid heterogeneous scaling on subjective indicators. Moreover, the experimental design was different for each type of LOA to keep perceptible but controllable situations. A 3*3 factorial design was used for LOA1 (Intensity: 0.1, 0.3 & 0.5; Duration: 250ms, 500ms & 750ms) (Table 2). A constrained design was used for LOA2 (Intensity: 0.1 to 0.6; Duration: 100 to 500ms). After each trial, a questionnaire was displayed with 13 questions about subjects' perception of the event (Table 1). Answers to the questions were given by the mean of continuous horizontal scroll bars representing two ends of a continuous scale (0: totally disagree to 10: totally agree) (Fig. 3) excepted for 4th question (Yes / No). Only LOA1 results are presented in this paper.

Behavioural measures (lateral position, steering angle, lateral acceleration, etc.) were recorded all along the trials at 20 Hz.

Table 1. Summary of the items corresponding to each question

Item	Question
Danger	"I perceived a danger during the bend"
Fear feeling	"I was afraid during the bend"
Feeling of control	"I easily kept my vehicle in the lane"
Perturbation perception	"Did you feel a perturbation in the bend?"
Intensity	"The LOA appeared to be weak/strong"
Duration	"The LOA appeared to be short/long"
Visual cue	"I visually perceived the LOA"
Haptic cue	"I perceived the LOA through the steering wheel"
Physical move	"I had the impression of physically moving"
Skid direction	"I felt the vehicle was skidding from the front/rear"
surprise	"I was surprised by the vehicle response"
realism	"Driving the simulator was unrealistic/realistic"
comfort	"I was at ease during the trial"

Figure 3. Visual answer interface of a question

Data analysis

For each condition, the mean and the standard deviation of the subjective answers were computed. When the fourth question was ticked “no”, the following answers were settled to a “default value” depending on the meaning of the question.

For each run, a time to stability (TTS) corresponding to the time taken by the driver after the onset of LOA to bring the vehicle drift speed back into a stability envelope was computed. This envelope is defined as the standard deviation of the mean drift speed and was measured in the control condition. Drift speed was calculated using the following formula: $\varphi_{drift} = \frac{d \arctan(\frac{v_y}{v_x})}{dt}$ with φ_{drift} the angular drift speed, v_x the longitudinal speed and v_y the lateral speed. The following objective data were observed in TTS interval: lateral deviation, steering wheel angle, slip angle, yaw speed and lateral acceleration.

Repeated measures analyses of variance (ANOVA, $\alpha = 0.05$) with the intensity and the duration of the LOA as independent variables (IV) were performed on the data. Scheffé tests were performed for post-hoc analyses. A principal component analysis was also performed on the subjective indicators in order to determine if they could be summarized by one or several underlying factors.

Results

Subjective data

The principal component analysis of the subjective data showed that all indicators can be represented by a single factor, which means that all variables were highly correlated. The simulation was globally judged as realistic (mean score = 7.64) with no significant effect of intensity and duration.

There was a significant effect of intensity and duration of LOA and a significant interaction between both IV on the duration and danger perception, fear and feeling of control. The effect of intensity and the interaction between both IV on perceived intensity was significant, but the effect of duration was not (Fig. 5 & Tab. 3). Post-hoc tests confirmed that the effect of intensity on duration, danger and intensity perception, fear and feeling of control was significantly higher for longer LOA.

There was no significant effect of the IV on the perceived direction of skidding. Participants could not tell if the vehicle was skidding from the front or the rear side (mean value: 5.11, SD: 2.7).

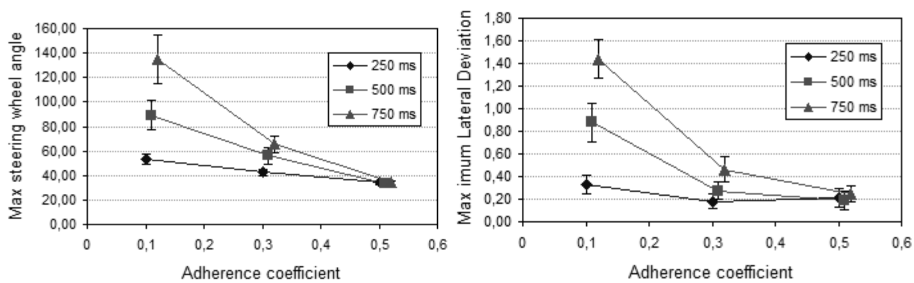
All the LOA situations were clearly perceived through the steering wheel (mean value: 8.13, SD: 2.35) and there was no significantly effect of the IV. Conversely, only the strongest LOA were perceived visually, as shown by the significant effect of the intensity ($F(2,38) = 62.53$, $p < .05$) and duration ($F(2,38) = 4.79$, $p < .05$)

Objective data

Intensity (F(2,38) = 200.97, p < .05), duration (F(2,38) = 57.65, p < .05) and interaction between both IV (F(4,76) = 13.14, p < .05) had significant effects on the TTS. Post-hoc test confirmed that the effect of intensity on TTS was significantly higher for long duration and that there was no significant effect of the duration for lower level of intensity.

Table 2. Maximum and mean TTS for each condition

Conditions	C1	C2	C3	C4	C5	C6	C7	C8	C9
Adherence coefficient	0.1	0.1	0.1	0.3	0.3	0.3	0.5	0.5	0.5
Duration (ms)	250	500	750	250	500	750	250	500	750
TTS max (s)	5.15	5.2	6.15	5.35	5.15	6.15	6.15	2.65	3.55
TTS mean (s)	3.02	4.13	5.55	2.18	3.2	3.93	1.14	1.07	1.44



(a) **(b)**

Figure 4. (a) ANOVA of the maximum steering wheel angle. (b) ANOVA of the maximum lateral deviation from the centre of the road

The ANOVA performed on the maximum steering wheel angle (Fig. 4a) showed a significant effect of intensity (F(2,38) = 136.7, p < .05) and duration (F(2,38) = 47.21, p < .05), with a significant interaction between both IV (F(4,76) = 23.08, p < .05). Similar results were observed on the maximum lateral deviation (Fig. 4b; intensity: F(2,38) = 125.48, p < .05, duration: F(2,38) = 97.08, p < .05; interaction: F(4,76) = 30.08, p < .05).

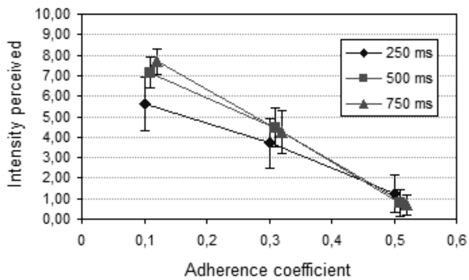


Figure 5a. Intensity perception

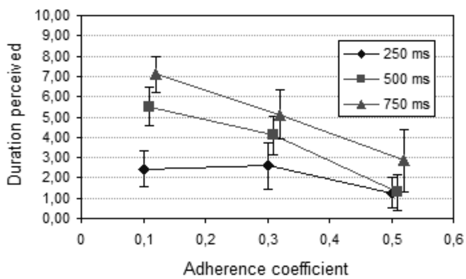


Figure 5b. Duration perception

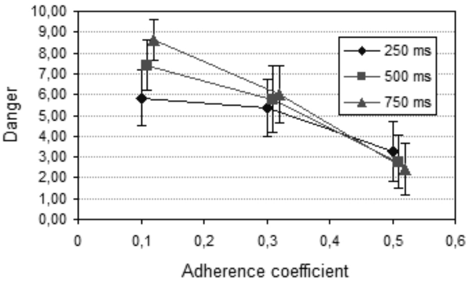


Figure 5c. Danger

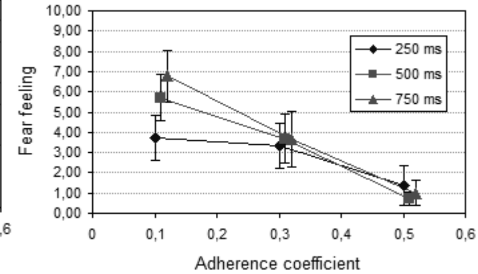


Figure 5d. Fear feeling

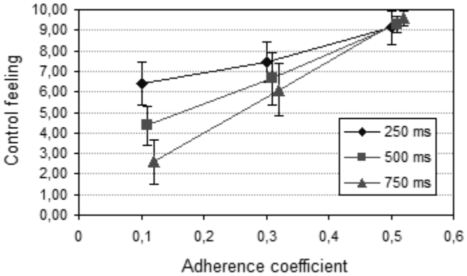


Figure 5e. Control feeling

Table 3. Summary of the statistical analyses performed on the effect of intensity and duration on the selected subjective variables

Subjective Items	IV	F	LoS
Intensity	Intensity	(2,38) = 108.47	**p < 0.05**
	Duration	(2,38) = 1.97	n.s.
	Intensity*Duration	(4,76) = 5.35	**p < 0.05**
Duration	Intensity	(2,38) = 34.78	**p < 0.05**
	Duration	(2,38) = 21	**p < 0.05**
	Intensity*Duration	(4,76) = 4.47	**p < 0.05**
Control feeling	Intensity	(2,38) = 89.58	**p < 0.05**
	Duration	(2,38) = 11.36	**p < 0.05**
	Intensity*Duration	(4,76) = 8.2	**p < 0.05**
Danger	Intensity	(2,38) = 63.04	**p < 0.05**
	Duration	(2,38) = 3.86	**p < 0.05**
	Intensity*Duration	(4,76) = 7.08	**p < 0.05**
Fear feeling	Intensity	(2,38) = 50.1	**p < 0.05**
	Duration	(2,38) = 6.67	**p < 0.05**
	Intensity*Duration	(4,76) = 7.3	**p < 0.05**

Discussion

From a general point of view, all subjective answers were correlated and can be described along one dimension, opposed to the adherence coefficient, as revealed by the principal component analysis. This suggests that all subjective ratings were coherent and determined by the intensity of the trajectory perturbation. The question remains now to determine if the participant were able to discriminate the magnitude and duration of the manipulated LOA.

The intensity of the LOA was perceived correctly with only minimal influence of the duration for the higher intensity of LOA. Interestingly, the perceived intensity was neither related to the maximum steering angle nor to the maximum lateral deviation. Since the maximum steering angle can be considered as a good indicator of the intensity of the steering correction, this suggests that subjects were able to evaluate how much adherence the vehicle lost, independently of how long it lasted and how much steering correction was needed.

By contrast, the duration of the LOA was poorly perceived. There was a strong interaction with the intensity of the LOA, revealing that the stronger it was, the longer it was perceived. It could be argued that the participant confused the duration of the LOA with the time needed to stabilize their vehicle, but the clear instructions given prior to the experiment make this assumption hardly believable.

A more plausible explanation is that LOA of high intensity were more stressful than milder one, as showed by the fear and danger ratings. Distortions of time have been observed under stress conditions, especially under life threatening conditions (Hancock, 2005) or during specific critical tasks by paramedics (Jurkovich, 1987). The underlying processes may be the attention. Indeed, Tse *et al*. (2004) proposed that novel or important events run in "slow motion" so that the information may be processed in greater depth per unit of objective time than are casual events.

Further experimentation with more experimented drivers on a high performances simulator with dynamic motion rendering should lead to more consistent results. Indeed, Kemeny *et al*. (2003) highlighted the importance of vestibular cues rendering in speed perception and steering in a simulator.

Conclusion

This study demonstrated that drivers are able to discriminate different conditions of LOA on a fixed-based simulator. Whereas the intensity of LOA episodes could be assessed by the driver with only minor distortions, a subjective expansion of their duration was observed. Further analyses will attempt to more clearly link subjective ratings and steering responses, and also to match the observed data with ESC triggering criteria.

Bibliography

Donges, E., (1978) A two-level model of driver steering behaviour. *Human Factors,* 20, 691–707.

Erke, A., (2008) Effects of electronic stability control (ESC) on accidents: A review of empirical evidence. *Accident analysis and prevention, vol. 40, n°1,* pp. 167-173.

Hancock P.A. and Weaver J.L., (2005) On time distortion under stress. *Theoretical issues in ergonomics science, 6:2,* 193-211.

Hoc J.M. & Amalberti R. (2007) *Cognitive control dynamics for reaching a satisficing performance in complex dynamic situations*. Journal of Cognitive Engineering and Decision Making, 1, 22-55.

Hollnagel E. (2004) *A function-centred approach to joint driver-vehicle system design*, Proceedings of the 2004 IEEE international Conference on Systems, Man and Cybernetics, pp. 2548-2551.

Jurkovich G.J., Campbell D., Padtra A. and Luterman A., (1987) Paramedic perception of elapsed time. *Journal of Trauma, 27,* 892-897.

Kemeny A., (2009) Driving simulation for virtual testing and perception studies. *Proceedings of Driving Simulation Conference Europe 2009*. 15-23.

Kemeny A., & Panerai F. (2003) Evaluating perception in driving simulation experiments. *Trends in cognitive science*. Vol 7-1, 31-37.

Land M. F., & Lee D. N., (1994) Where we look when we steer. *Nature, 369,* 742–744.

Lechner D., Delanne Y., Schaefer G., Schmitt V., (1997) Méthodologie de validation du logiciel de dynamique automobile CALLAS. *SIA 970202.* Congrès SIA Lyon, Avril 1997. Reprinted in Ingénieurs de l'automobile N°713, Mai 1997.

Liebemann E.K., Meder K., Schuh J. and Nenninger G., (2004) Safety and Performance Enhancement: The Bosch Electronic Stability Control (ESP). *SAE Paper No. 2004-21-0060.*

Mellert V., Baumann I., Freese N. and Weber R., (2007) Impact of sound and vibration on health, travel comfort and performance of flight attendants pilots. *Aerospace Science and Technology, 12,* 18-25.

Michon J.A. (1985) A critical view of driver behavior models: what do we know, what should we do*?. In: L. Evans and R.C. Schwing, Editors, Human behavior and traffic safety, Plenum, New York,* pp. 485–520.

Papelis Y.E., Watson G.S. and Brown T.L. (2010) An empirical study of the effectiveness of electronic stability control system in reducing loss of vehicle control. *Accident Analysis and Prevention, 42,* 929-934.

Reymond G., Kemeny A., Droulez J., Berthoz A. (2001) Role of lateral acceleration in curve driving: Driver model and experiments on a real vehicle and a driving simulator*, Human Factors, 43*, 483-495.

Strigler F., Touraille C., Sauvageot F., Barthélémy J. and Issanchou S., (1998) « Les épreuves » in *évaluation sensorielle : manuelle méthodologique, sous la direction de SSHA, Depledt F., Strigler F. Ed. Lavoisier.*

Toffin D., Reymond G., Kemeny A., Droulez J.,(2007) Role of steering wheel feedback on driver performance: driving simulator and modeling analysis, *Vehicle System Dynamics, 45*, 375-388.

Tse P.U., Intriligator J., Rivest J. and Cavanagh P., (2004) Attention and the subjective expansion of time. *Perception and psychophysics, 2004,66(7),* 1171-1189

Williams E. J., (1949) Experimental designs balanced for the estimation of residual effects of treatments. *Australian Journal of Scientific Research, Ser. A 2,* 149-168.