Optimization of Linear Motion Base Dedicated to Normal Driving Conditions

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Abstract

One of the major problems of the current driving simulators results from the difficulty, for the users, to perceive the small variations of longitudinal velocities, perception necessary in platoon driving and for braking control. The reproduction of this fundamental aspect, is one of the major limitations in most research works.

The study proposed here, uses a 2 DOF motion platform prototype. This motion-base enables to investigate larger longitudinal movements and larger bandwidth than a 6 DOF platform, for a same cost. Such longitudinal acceleration rendering appears particularly relevant for the study of car-following or emergency braking situations. Our study aims to explore various longitudinal movement configurations, to determine the optimal combination which recreates at best the sensation of longitudinal accelerations one driver may feel during platooning situation.

A comparison, in car-following situation, between various objective criteria (such as variations and frequencies of accelerations, coupled with more subjective observations concerning comfort and realism of the simulations) has been used to organize these configuration of motion in terms of restitution relevance. From a behavioural standpoint, to compensate methodological and statistical problems inherent to the between-subject variability in driving behaviours habits, participants were identified according to their apprehension of the visual environment (EFT), their driving habits (MDBQ) and their causal allocation style (LOC).

Results shown that the association between short longitudinal motion and back of the seat tilt, seemed to favour the vehicle control sensation. This report is all the more true that participants are usually good drivers.

Introduction

The driving activity could be defined as a complex task, where drivers must continuously interact with her/his environment to manoeuvre through the traffic and obstacles on the road. To study such activity, the whole parameters included in this interaction (driver, vehicle and environmental specificities) should necessarily be taken into account. However, it is not easy to define the degree of implication of each of those parameters. Since, conventional road tests are difficult to install, for safety, cost and/or methodological reasons, driving simulation seems to be an attractive alternative. First, because it is a safe and economical mean of testing driving performance. Second, because it can provide accurate observations on drivers behaviours and functions.

Before a simulator can be used as vehicle development system valuator or as human testing tool, one must consider the ability of the simulator to reproduce the sensations of a real vehicle. The main difference between fixed-base simulation and reality lies in the mismatch between the perception of speed and time to collision (Boer, 2000). In that case, drivers have to adapt their behaviours, what entails an increase of the attentional demand and the workload, translated by an increase of the response time.

To favour the transfer between the real and the simulated situation, one can consider the importance of mimicking the contexts of application (Godden & Baddeley, 1975; Reder & Klatzky, 1994). This, ask the question of the driving simulator validity. In this area a distinction is usually made between four kinds of validities: physical, perceptual, relative behavioural and absolute behavioural validity. The physical validity (Blaauw, 1982) refers to the physical correspondence between driving simulator, and the real car. The perceptual validity refers to the driver's perception on these two situations. The relative behavioural or predictive validity (Blaauw, 1982; Blana & Golias, 1999) includes contextual effects (road, vehicle, traffic condition) in driving behaviour comparison. Such validity mainly differs from the absolute behavioural validity by the fact that relative validity limits itself to the qualitative aspects of the comparison between simulated and real situation while the absolute validity includes the quantitative aspects. Those validities are often separately considered. In our experiment we have tried to take into account physical, perceptual and relative behavioural validities. According to Törnos (1998), absolute validity is not essential, for a simulator to be a useful research tool.

Either on the most "advanced" DS (i.e. the most complex ones), it is impossible to render acceleration at scale 1, particularly for longitudinal ones. That necessarily reduces physical validity and drivers may not receive the same feedback as in a real vehicle. One of the most intuitive and widespread ideas is to consider that a moving-base simulators have a greater validity than a fixed-base simulators, but this assumption depends on a lot of factors and must be proven for each prototype and for each type of usage. A sophisticated simulator may not have necessarily a greater validity than a less sophisticated and less expensive simulator (Triggs, 1996).

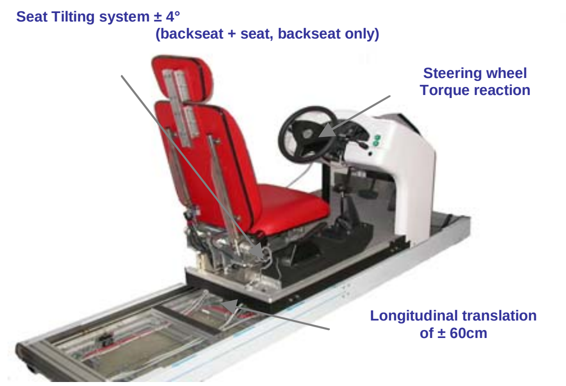
The aim of this study was to identify what configuration of minimal motion, applied to the simulator, could_give to the drivers, the illusion that they evolved inside a real car.

This is why we have proposed a simulator with only 2 degrees of freedom dedicated to platooning situations. The first was referred to the longitudinal movements, the other to the tilt of the back of the seat.

Simulator prototype

The aim of the longitudinal system was to reproduce exclusively transitory accelerations. These accelerations were the result of a high-pass filter applied on the longitudinal acceleration stemming from the simulated vehicle model. After a double integration of the transitory component of the longitudinal acceleration, a reference position was computed. To put back the platform (fig.1) to its rest position, during the continuous acceleration, a second high-pass filter was applied on the reference position. With this attention, the back of the seat was moved into the opposite direction to the plat-form displacement. The aim of the back tilt system was to reproduce the transitory accelerations generated by the vehicle acceleration on the driver chest. The angular acceleration which would normally act on the driver was computed and a classical cueing algorithm mimicked it and generated the appropriated tilt.

Figure 1: INRETS MSIS prototype



Method

In addition to the mechanical considerations, the question of the human component in the simulator validation has also been raise. In the literature, individual characteristics are not usually considered as potentially informative factors as regards the validity of the driving simulator. Most of reports focus on main effects of the psychological factors problems, rather than on interactive or moderating effects of individual variables. We included this aspect in our experiment: first, because in the reality between-subject specificities reflect the co-occurrence of those variables; second, because one can investigate the moderating role of certain factors on others; third, because such approach could enable to determine if certain groups of drivers may cancel relevant effects of the driving simulator's mechanical parameters.

Then it appeared necessary to consider several individuals characteristics to determine whether the nature of motion restitution have an idiosyncratic effect on driver or if we can define a common configuration appreciated by the majority, especially interesting prospect if the motion base is intended to drivers training.

Our experiment was designed to pave the way for future simulators which will investigate the effects of different motion restitutions onto driving simulator performances. The theoretical hypothesis according to which a worse longitudinal restitution will induce larger time headway, because of a lack of control on the vehicle, has been tested. As regards individual characteristics, that would mean that subjects who are usually prudent, will be all the more prudent that they won't manage to control their vehicle. In the same way, subjects who are particularly sensitive to inertial cues will be more reactive to the motions of the simulator than the others. Their driving performances will change with the different conditions of the platform motion restitution.

Experimental design

A two-factor (Back of the seat*motion base) repeated measure design was used, where Seat variable consists of two levels (Back of the seat tilt On, Back of the seat tilt Off) and the magnitude of the platform motion of three levels (Without, Short, Long longitudinal movement). All of these 2*3 experimental conditions (see table I), requires that the subjects drive the simulator for five minutes on average.

Table I: Experimental Conditions

Experimental Condition	Back of the seat Tilt **Off**			Back of the seat Tilt **On** (± 4°)		
	Without longitudinal Motion	**S**hort (± 10cm) longitudinal Motion	**L**ong (±30cm) longitudinal Motion	**W**ithout longitudinal Motion	**S**hort (± 10cm) longitudinal Motion	**L**ong (±30cm) longitudinal Motion
Abbreviation	**W_Off**	**S_Off**	**L_Off**	**W_On**	**S_On**	**L_On**

Participant profile

32 people participated to the experiment. All of them were healthy adult range from 19 to 62; eleven were female and twenty one male. Participants were recruited by advertising on the INRETS Arcueil site and through personal contact, and have current driving licences. All have normal or corrected-to-normal vision and none reports vestibular abnormalities. Most had never used driving simulator before. Those who had used it were only been confronted to a fixed-base simulator.

Apparatus

Driving simulator

Participants drove in a moving-base driving simulator (INRETS MSIS SIM² class), with dynamic and interactive visual image. Three PC rendered and updated the visual scene *via* Performer Software. Such scene was projected onto a 3 large screens (H: 150°- V: 45°) at 2.80 m in front of the driver seat, with Barco CRT 808S video projectors and was continually changed at rate of 60 Hz in accordance with the displacement of the virtual car. For local motion base movements, corrections for the position were not made in projected scene because they can induce supplementary transport delay. Moreover this longitudinal motion in the same direction as the virtual movement of the subject brought an error of speed and acceleration which can be considered here as negligible. During the pre-experiments no subject noticed it. The simulation also contained a three dimensional sound system, reproducing engine and aerodynamics noises. In this aim, a 4.1 audio system was used.

Sub tests

Three individual characteristics related to the driving activity were investigated: the driver's habits, the internality belief style, and the visual field dependence. Badly driving habits were estimated by a French version of the Manchester driving behaviour questionnaire (MDBQ).

Because the degree of which an individual feels in control of behavioural outcomes is related to risky driving (Hoyt, 1973; Phares, 1978; Williams, 1972), we consider here their locus of control (LOC Rotter, 1966) through the Internality-Externality scale (I_E scale). The LOC construct refers to the extend of which persons view significant events in their lives as generally being the result of their own actions (internal locus of control), or the result of uncontrollable factors and forces (external locus of control).

Finally, because we worked on the inertial information restitution and on the driving performances, we also considered the degree of visual field independence of our participants (Witkin & Ash, 1948). This perceptual style, largely linked with the activity of driving (Rogé, 1996) was measured by the Embedded Figures Tests (EFT).

Measurements

Subjective recording

The main subjective dependant variable was the rank allocated to each condition. If the participants did not succeed in ordering strictly these conditions they could proceed to equalities in their classification. We also considered the comments of the drivers as regards the realism of deceleration, acceleration and braking manoeuvre.

Objective recording

The objective dependant variables were the mean headway time (HT), the response time (RT), the time to collision (TTC) and the variation of decelerations (VAR_{dec}). (1) HT refers to the delay between the lead vehicle and the simulator. (2) RT refers to the delay between the start of lead vehicle action and the reaction (braking or engine braking) of the driver. (3) TTC refers to the delay before impact. (4) the VAR_{dec} refers to the changes of deceleration of the piloted vehicle.

Experimental Procedure

Subjects were informed about the nature of the experiment and asked to complete the sub-tests. They were instructed to follow a lead car and to respect safety distance. They can not overtake due to the traffic situation (i.e. vehicle coming in reverse sense). It was explained that during the experiment some symptoms may occur and they are informed that they can withdraw at any time, for any reasons. Each volunteer was asked to answer demographic questions on their age, gender, driving practice, and to complete the 28-items of a French version of the MDBQ and the I_E scale. They were also submitted to the EFT. Those sub-tests allowed to determine not only the way of which each participant perceives and reacts to his/her environment, but also to illustrate the between-subject differences as regards the dependant variables usually observed in real driving situation (Grubb, 1992; Lambert & Fleury, 1994-1996; Pottier & Pottier, 1989).

In each sequence of driving, we implicitly forced participant to react to accelerations and decelerations of the lead car. To make the driving situation as ecological as possible, direct and indirect contextual cues (brake lights, indicators, road signs, village, roads works) induced the lead car velocity changes. So, all manoeuvres of the lead car were more or less foreseeable. The order of the experimental conditions and visual environment was counterbalanced between participants.

Data collection and analyses

At the end of each of the simulations the subject proposed a classification between the experimented conditions. When the six conditions were ended, the experimenter recapitulated with the subject, the order in which he had classified all the conditions. In case of equality between two or several conditions, the experimenter insisted on the idea of a differentiation. If however certain equalities are maintained, they were taken into account in the final analyses. For each of the lead car events, five measurements were recorded at a rate of 10 Hz. From the lead and the piloted cars we have recorded their distance from the start of the road; their speed and acceleration, and for the piloted car only, intensity of the press on the braking pedal and the slow down. From all of those records, the HT, RT, TTC and VAR_{dec} were computed.

Results

2 subjects withdrew after the first experimental condition because of severe simulator sickness symptoms. Their data were not used in the analyses.

Subjective estimates

Numbers by rank and by conditions are reported in table II. Since several people granted equivalent places for various conditions, we proceeded to an analysis by condition. Two conditions have their modes in the first position S_On and W_On. Those two proportions, respectively 56 and 40 %, statistically differ (p = 0.09). S_On obtained more votes than W_On.

Table III: Classification of the experimental condition.

	1st Position	2nd Position	3rd Position	4th Position	5th Position	6th Position	Sample
W_Off	5	3	5	3	***9***	5	30
S_Off	7	8	5	6	2	2	30
L_Off	4	4	***10***	6	4	2	30
W_On	***12***	7	4	4	3	0	30
S_On	***17***	3	7	1	2	0	30
L_On	6	7	3	6	5	3	30

Values in bold and italic are statistically different from the hazard, and from the other line values.

One third of participants graded the L_Off situation as an intermediate (third position). 33% consider W_Off as the worse. There is no consensus as regards the two others experimental conditions.

Driving performances

Relationship between dependant variables: The first observation concerns the significant correlation between all of the objective dependent variables, with however a tendency between RT and TTC. In other words, people whom adopt high HT have also high RT and high TTC. The negative correlation with the VAR_{dec} measure indicates that high HT is associated with a small VAR_{dec} .

Experimental conditions and HT (fig. 2): The non-parametric Friedman analysis reveals a general effect of the tilt of the back of the seat ($Chi^2(1) = 3.33$; $p < .06$). The Mann-Whitney rank comparison shows that the mean HT is smaller when the back of the seat tilts than when it doesn't ($Z = 1.71$; $p < .08$).

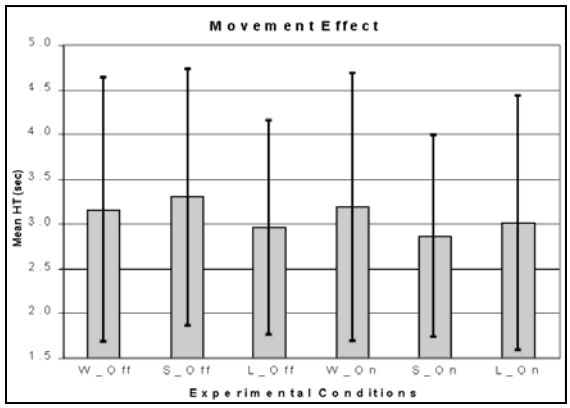


Figure 2: Mean HT practiced during experimental condition

We also noticed a general effect of the combination of motion (seat + motion base) ($Chi^2(2) = 6.06$; $p < .04$) on the HT. They significantly differ in S_On and L_On as regards the W_On condition ($Z = 2.12$; $p <.03$). The Mann-Whitney rank comparison reveals more precisely that the mean HT in W_On is lower than the mean HT in S_On ($Z =2.17$; $p < .03$). No other effects and comparisons are statistically significant.

Individual characteristics and objective dependant variables: Correlations analyses between scores in individual scales and dependant variables have revealed that only the MDBQ scores were linked with HT, RT and VAR_{dec} (Table III).

Table III: Spearman range correlation coefficient between individual scales and objective dependant variables.

EFT	Spearman r
HT	-0.05
RT	0.09
TTC	0.05
VAR_{dec}	0.05

MDBQ	**Spearman r**
HT	**-0.42**
RT	**-0.46**
TTC	**-0.24**
VAR_{dec}	**0.45**

LOC	Spearman r
HT	0.10
RT	-0.01
TTC	0.21
VAR_{dec}	-0.22

Results of MDBQ have allowed distinguishing three populations. Those who respect the French traffic rules, and drive prudently (P); those who don't respect these rules, the risky behaviours (R) and intermediates (I). We have considered here only extreme people (P *versus* R). The Mann-Whitney rank comparison shows that the mean HT between those two populations differs ($Z=-2.72$, $p = 0.006$), it is globally higher for P. If we separately consider these populations, the non-parametric Friedman analysis reports no experimental condition effects for R, in comparison to P people (respectively Chi ² (N = 10, dl = 5) = 2.68 $p < .74$ for R and Chi ² (N = 10, dl = 5) = 13.42 $p < .01$ for P).

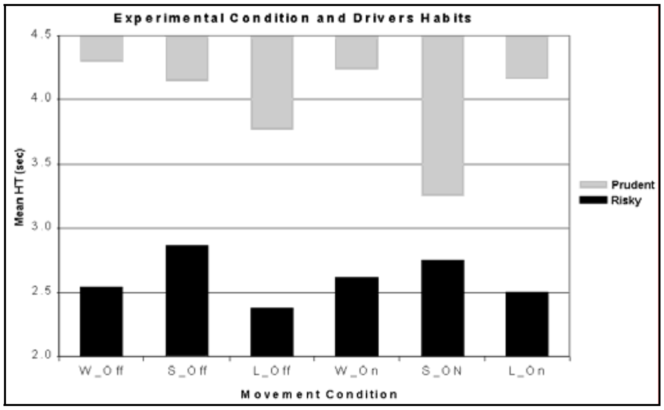


Figure 3 : Mean HT as regards experimental conditions and subjects driving habits

The P drivers mean HT decreases for the S_On displacement (fig. 3). The *t-test* shows that P and R performances in this condition doesn't differ (t(18)=1.001, p = 0.33). No significant effects were observed with the other individual characteristics.

Discussion and perspectives

The main objective of this research was to assess the relevance of our driving simulator architecture choice (longitudinal + back of seat motion) and to compare different modalities for longitudinal accelerations rendering. A secondary aim was to support the use of individual characteristic measures as potential indices for the assessment of new driving simulators. It appears that the longitudinal displacement of the motion-base alone is not sufficient to modulate the driving performances in comparison to the lack of platform motion. However the tilt of the back of the seat provides information that modulate them.

One can interpret the decrease of the HT in S_On condition, as an increase of confidence and may be as an increase of the virtual vehicle control. We also remind that this condition is subjectively considered as the better among the six experimental conditions proposed in our experiment. Such interpretation is reinforced by the fact that the MDBQ individual parameter offers a same kind of result, but for prudent drivers exclusively.

Conclusion

We have shown in this experiment that it was possible to propose a low-cost driving simulator for studies dedicated to platooning situations. According to the task and the environmental specificities, the efficiency of the amplitude of the reproduced longitudinal motion seems to vary. More precisely, from a subjective point of view, short longitudinal motion of the platform associated with a tilt of the back of the seat seems to be appropriate for normal traffic situations, while long motions seem more convincing for the emergency braking. Long motion might be then, specifically employed to study driver assistance systems like the E.B.A. (Emergency Braking Assistance) for example.

Validation of a driving simulator, from a perceptual point of view, is an extremely important step to qualify the simulator as a productive tool (reducing time and costs in prototyping new solutions) and as realistic and controlled environment for the study of driver's behaviours. This experiment has allowed demonstrating the interest to identify the population who has the greater probability to react to the variation of the studied parameters. In our situation of car-following, the relevant characteristic concerns the driver’s habits. The effects of the different restitutions were observed only for subjects who have the habit to respect the French rules of driving.

Since it is a first experiment on the INRETS moving-base driving simulator, all of those results and interpretations must be confirmed. A psychophysical study could allow improving the results, notably as regards very short movements. Even though we did not manage to determine the role of the inertial field dependence in our experiment, this individual characteristic could intervene in other driving situations.

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