PRESENCE STUDIED IN A DRIVING SIMULATOR

Christophe DENIAUD [1,2], Vincent HONNET[2], Benoît JEANNE[2], Daniel MESTRE[1]

(1): The Institute of Movement Sciences, University Aix-Marseille II, 163 av. de Luminy, 13009 Marseille France. {christophe.deniaud, daniel.mestre}@univ-amu.fr

(2): PSA Peugeot Citroën Route de Gisy 78140 Vélizy-Villacoublay France {christophe.deniaud, vincent.honnet, benoit.jeanne}@mpsa.com

Abstract – In this paper, our ambition is to find a way of measuring "presence" to use it as a measure for ecological validity in driving simulators. The underlying assumption is that a person experiencing a strong sense of presence in the virtual environment will react in this environment as if it would be a real one. We propose to measure "presence" by measuring "attention" toward the driving task". Our objective is to demonstrate that the higher the subject's attention required by the primary driving task will be, the more the spatial presence will be felt. In the experiment we tried to vary "attention" by adding a dual task and by adding traffic and measure driving performance and subjective "presence". The main result is a lack of congruence between subjective and behavioral measures.

Key words: Driving simulator, spatial presence, attention, ecological validity, cognitive involvement

1. Introduction

In the 1960s, driving simulation was mainly used to train specific target audiences such as novice drivers, law enforcement officers and truck drivers [All3]. Since then, many advances have been achieved in terms of computing, visual display and vehicle dynamics rendering [All2]. Driving simulation was originally developed to avoid cost of field studies, allowing more control over circumstances and measurements, and ensuring safety in hazardous conditions [All1]. In the second half of the twentieth century, simulation was being successfully applied to aeronautical, rail and maritime operations. In spite of significant differences, it is interesting to note that the development of driving simulation was based on the development of flight simulation. Driving is a dynamic task with a set of rapid control maneuvers involving critical feedback for avoiding obstacles and preventing crashes [Han9]. Compared to the activity performed by air line pilots, driving involves higher amplitude, and higher frequency cues. The motion feedback doesn't play a key role for the major part of slow maneuvers performed by civilian pilots. Indeed there is no evidence that motion base-simulators are more efficient than fixed base simulators for training of commercial pilots [Bür6]. Thus there is a stark contrast between driving simulation and flight simulation (Civil aviation only). Compared to an air line pilot, a driver needs a higher degree of motion simulation. That is probably the reason why the use of flight simulators is more than commonplace for pilot training and, conversely driving simulators are not widely used for driver training due to the inherent higher complexity of the driving task. Nowadays driving simulators are usually designed for two purposes: research and training. The simulator is essentially used to place constraints on driver behavior in order to study driver distraction and workload or used as test beds for highway design [Kan14]. The use of a modern advanced driving simulator for human factors research has many advantages such as experimental control, efficiency, expense, safety, and ease of data collection [Nil19]. However, the literature describes some possible disadvantages, i.e. simulator sickness, accurate replication of physical sensations, and most importantly, validity.

2. Ecological Validity

In spite of significant advancements in the physical fidelity of the driving simulation, a lack of realism seems to be always observed in the major part of driving simulator studies [All4]. The most important question is to know in which extent measures from simulation are similar to those obtained in the real world. This multidimensional problem is called simulation validation [Bla5]. This question has been a concern for at least 25 years. Blaauw (1982) defined two types of validity. The first is the absolute validity, it deals with the extent to which a manipulation of a variable in the real world produces the same or equivalent change in the same measure when manipulated in a driving simulator. The second is called the relative validity it refers to the extent to which the direction of change of a variable is in the same direction as a corresponding manipulation and measure in the real world [Kap15]. If absolute validity is obviously desired by researchers, regarding the variability of driver performance, it seems highly unlikely to have an exact correspondence of on-road and simulation measures. Furthermore there is no bad or good simulator from a methodological point of view. The simulation validation seems to be arbitrated between the research issue and how simulators are used to investigate this question. Each simulator must be validated for a specific use. In addition, the question of simulation validation has followed the perpetual development of a significant number of simulator components as computers and various display technologies. That is the reason why, since four decades, simulators have been designed to deliver more and more perceptual cues to the driver in order to reproduce as accurately as possible the experience of driving an automobile. Thus, simulator validity is often addressed in the extent to which a physical variable in a simulator corresponds to its operationally equivalent component in the real world is called Physical fidelity [Lee18]. As previously discussed, simulation validity is multidimensional and can be related to behavioral and physical dimensions [Jam11] but also to the perceived sensation of the subjective experience and objective performance. Indeed, despite significant advancements in the fidelity of the driving experience driving simulator studies continue to be criticized for lack of realism [Goo8]. More specifically, the physical fidelity of the driving experience appears insufficient to overcome criticisms concerning the lack of psychological fidelity [Goo7], defined as the extent to which the risks and rewards of participation in the experiment correspond to real-world risks and rewards [Ran20]. The main problem is that driving experimental studies failed to provide a non-artificial trip purpose which could be able to reproduce drivers' motives inherent to the real driving activity. Generally, it appears that the assessment of the validity of the virtual environment involves the comparison of results obtained from studies conducted in real situations and in virtual environment. However, this comparison is expensive (instrumentation) and complex (strict control of all the events occurring in a real situation). This is probably the reason why questions about the validity of simulators are most often pending [Rei22] and why only few studies on this question can be found.

3. The concept of presence: a methodological alternative to assess the ecological validity in driving simulators

In this paper, a new approach is developed. We propose to understand the behavior similarities between real and virtual environment through the concept of presence which will be clearly explained in the continuation of our lecture. The validity issue requires to not opposite physical validity to psychological validity. The main idea is to find a methodological tradeoff, based on behavioral and psychological considerations in order to investigate the ecological validity of simulators. We argue in favor of a phenomenological approach understanding experience as the source of all knowledge. More specifically, it deals with the necessity to overcome the dualism developed by Descartes assuming that mind and body are not identical. In understanding the legitimacy of our theoretical approach we quickly expose the paradigm of virtual reality upon which the driving simulation also rests. Driving simulation is a historical component of virtual reality, the purpose of which being to enable one person (or more) to develop sensori-motor and cognitive activity in an artificial world [Kem16]. The interaction of a person with the virtual world is a transposition of the perception-cognition-action loop of human behaviour in the real world. Immersion in a virtual world cannot be the same as in the real world [Ijs10] since the user has learned to act naturally in a real and physical world (without, for instance, any delay and/or sensorimotor bias). Thus, immersion, depending on the sensorimotor contingencies permitted by the simulator, is a necessary but not sufficient condition for the expression, within the virtual environment, of a performance that is representative of the actual situation [Lee17]. Facing this problem, a concept emerged in the '80s from the early steps of research about virtual reality. This concept addresses the issue of "ecological" validity of the behaviour observed in virtual environments. It is the concept of presence. This multidimensional concept is considered as the ability of individuals to adopt behavioural patterns similar to that observed in everyday life and therefore as their propensity to respond to various stimuli by a realistic way [Sla25]. Some studies [Joh13, Tic27] already proposed this concept as a tool for assessing driving or railway simulators but only in driving situations generating a state of stress. In studies about presence, finding a consensus about presence conceptualization in order to enhance its operationalization and its assessment [Sla26] seems to be the main challenge. Various attempts have been made to describe this concept. Despite divergences, the major part of publications considers that presence rests on an attentional basis [Reg21, Sch24]. Among the previous attempts to develop a unified approach for spatial presence, a model developed in 2007 caught our attention (see figure1). It is made of two levels: the first level involves the construction of an unconscious mental representation of space (the spatial situational model), allowing in a second level a conscious percept of subjective presence (spatial presence). The novelty of this model is therefore based on the fact that it offers a description of subjective processes involved in the emergence of the feeling of presence. In the MEC model of spatial presence, it clearly appears that the formation of a spatial situational model is a key concept for the emergence of presence.

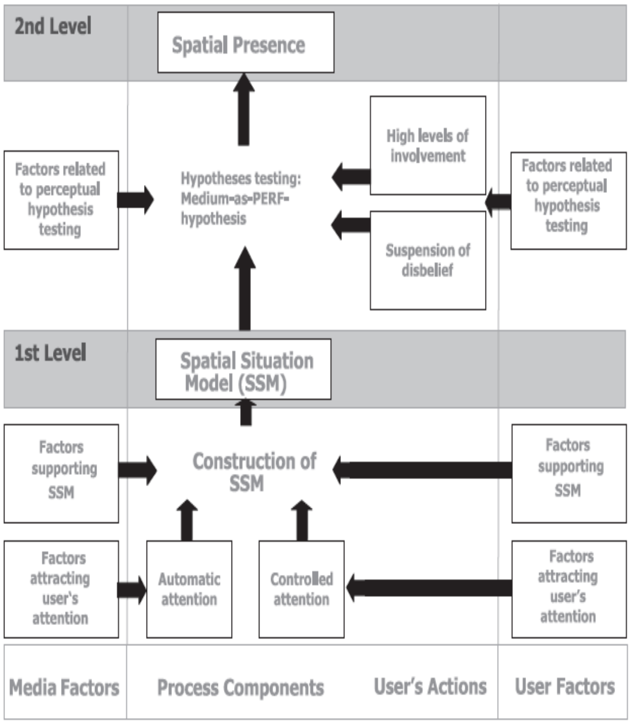

Fig. 1. MEC Model of Spatial Presence

Furthermore we notice that the spatial situational model is clearly the result of automatic and controlled attentional processes. Thus, we decided to modulate experimentally the cognitive load induced during the simulated driving task, in order to generate different attentional states and finally to induce different levels of spatial presence. We crossed the following 2 independent variables: 1) A secondary task (dual-task paradigm), supposed to distract the driver from the primary task (driving) and 2) the presence of traffic on the roadway, supposed to focus the driver’s attention toward the primary task. . Our objective was to develop a sensitive measure of presence in order to assess the simulator validity. To do so, we decided to test the attentional assumption developed in the MEC model of spatial presence. According to the two-level model of spatial presence, the measurement of presence can be approached in two different ways [Sch23]. On the one hand, we have to evaluate the behavioral dimension of the activity which describes the first level pretty unconscious. To do so, we analyzed the driving performance. On the other hand, we have to evaluate the conscious subjective experience of physical presence by a qualitative method. We thus used the MEC Spatial Presence Questionnaire (MEC-SPQ).
Our main hypotheses were:

-H1: The vehicle traffic in the virtual world is a positive predictor of the different sections of the MEC -SPQ
-H2: A dual task performed during the driving is a negative predictor of the different sections of the MEC-SPQ

4. Method

4.1. Participants

Twenty experienced car drivers, with at least five years of experience (14 men and 6 women), were divided into four groups, by crossing two independent variables, i.e. a dual task to be performed or not during the experiment and the presence or not of other vehicles' traffic on the road. The age of the participants ranged from 22 to 45 (M=32.8 years, SD=6.45). All were tested on a voluntary basis, having signed an informed consent form.

4.2. Apparatus

The experiment was carried out using the SIM²-IFSTTAR fixed-base driving simulator equipped with an ARCHISIM object database SIM2. The projected display (at 30 Hz) presented a field of view of 150° horizontally and 40° vertically. The simulator's cockpit (see figure2) contained a microcontroller managing a force feedback steering wheel, 3 pedals (accelerator, brake, clutch), a gear box, a display dial (speedometer, a tachometer) and different switches (wipers , lights…). Driving performance was recorded online and stored for offline analysis

4.3. Procedure

In our experiment we used a digital model of the Versailles Satory runway, which is a closed loop of 3.7km, with long straights and corners with different radii of curvature. The first factor was the level of attention induced by the virtual environment with two levels: automated bidirectional traffic or not. The second factor was the level of cognitive involvement induced by the real world with two levels: presence of a dual task or not. The secondary task consisted in launching every minute a digital hourglass by double clicking the mouse of a laptop positioned so that the person had to deport his gaze from the main visual scene. Half of the subjects had to perform the dual task, either in condition "traffic", or in condition "no traffic" on the Satory circuit. It is important to note that this dual task was used as a manipulation device and not as a performance measurement. That is the reason why reaction times were not presented in this paper. Whatever the experimental conditions, each participant had to perform 10 laps with a maximum speed of 110 km/h by respecting the Highway Code.

Table 1. Experimental design

	Dual task	Traffic
Group1	No	Yes
Group2	Yes	Yes
Group3	No	No
Group4	Yes	No

We applied a 2 X 2 factorial design. Four experimental groups of five subjects were thus created (see table1).

4.4. MEC (Measurement, Effects, Conditions) Spatial Presence Questionnaire

After each session an adapted version of the MEC Spatial Presence Questionnaire (MEC-SPQ) [Vor28] was used. As suggested for each scale, we used a 5-point Likert scale ranging from 1 ('I do not agree at all') to 5 ('I fully agree'). We used 4-item scales for the tested dimensions. On the first level, visual spatial imagery (VSI) was assessed with items such as " When someone describes a space to me, it's usually very easy for me to imagine it clearly"; for allocation of attention "I dedicated myself completely to the medium"; for the spatial situational model (SSM) " I was able to imagine the arrangement of the spaces presented in the medium very well". On the second level, higher cognitive involvement (CogInv) was assessed with items such as " I thought most about things having to do with the medium"; for suspension of disbelief (Sod)" I didn't really pay attention to the existence of errors or inconsistencies in the medium". Finally, spatial presence was measured and analysed by the self-location dimension (e.g., «I felt as though I was physically present in the environment of the presentation").

4.5. Driving performance

We analyzed two behavioral variables reflecting the driving performance, i.e. means and standard deviations of speed and of lateral position (SDLP).

5. Results

5.1. MEC spatial presence questionnaire

A mean score was computed for each group for the various dimensions of the MEC SPQ (see figure2). Overall, Whatever the section of the questionnaire, participants reported rather high scores. Specifically, "attention" scale (M= 4.2; SD=0.70) had the highest score while "cognitive involvement" scale (M=3.33; SD=0.95) had the lowest.

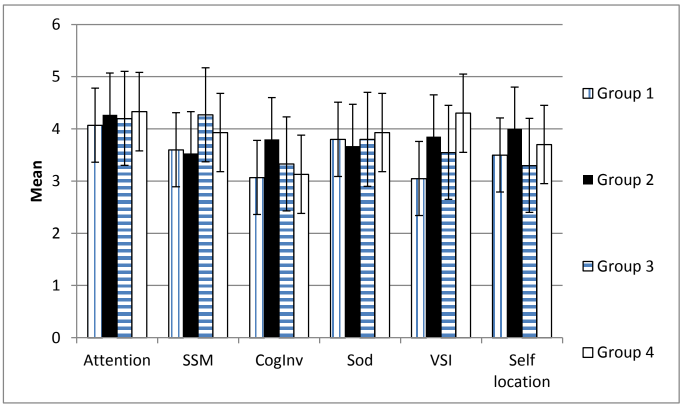

Fig. 2. Mean of MEC Spatial Presence Questionnaire Sections

The generalized linear model was used in order to test our hypotheses, with a 2x2 factorial design and independent groups. Then multivariate analysis of variance (MANOVA) was considered for assessing interaction effects between independent variables.

Table 2. Manova results (statistical significance set at p<0.5)

	Dual Task	Traffic	Dual Task*Traffic
Attention	F=0.24 P=0.63	F=0.09 P=0.77	F=0.01 P=0.92
Spatial Situation Model (SSM)	F=0.58 P=0.48	F=4.13 P=0.06	F=0.26 P=0.62
Cognitive Involvement (CogInv)	F=0.36 P=0.56	F=0.20 P=0.66	F=1.11 P=0.31
Suspension Of Disbelief (Sod)	F=0 P=1	F=0.17 P=0.69	F=0.17 P=0.69
Visual Spatial Imagery (VSI)	F=4.48 P=0.05	F=1.68 P=0.21	F=0.01 P=0.95
Self-Location	F=1.48 P=0.24	F=0.46 P=0.51	F=0.02 P=0.89

From the MANOVA analysis, no interaction effect was observed between the traffic condition and the dual task condition (see Table2). Whatever the experimental condition no significant effect was observed on the various sections of the MEC Spatial Presence Questionnaire. Contrary to what was expected, the dual task and the traffic had no impact on the questionnaire results.

5.2. Driving performance

5.2.1. Lateral position

An interaction effect was first observed between dual task and traffic (F(1, 360)=28.827;p<0.01). Lateral positions of Groups 1 and 2 submitted to traffic were higher than those of groups 3 and 4 not submitted to traffic (see figure 3).

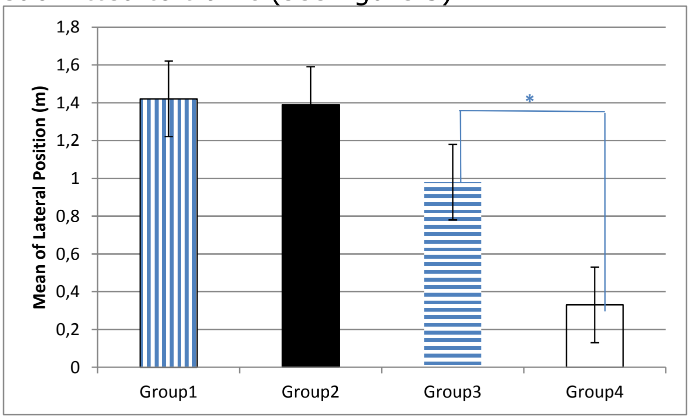

Fig. 3. Mean of lateral position (m)

A dual task effect is also observed in the absence of traffic, (F(1,360)=35.27, p<0.01). Indeed, subjects not submitted to the dual task (Group3) had a higher mean lateral position compared to subjects submitted to the dual task (Group4).

5.2.2. Speed

A dual task effect was observed (F(9,360)=2.33;p=0.012) on 10 laps performed between groups not submitted to the dual task (group 1 and group 3) and groups submitted to the dual task (group 2 and group 4).

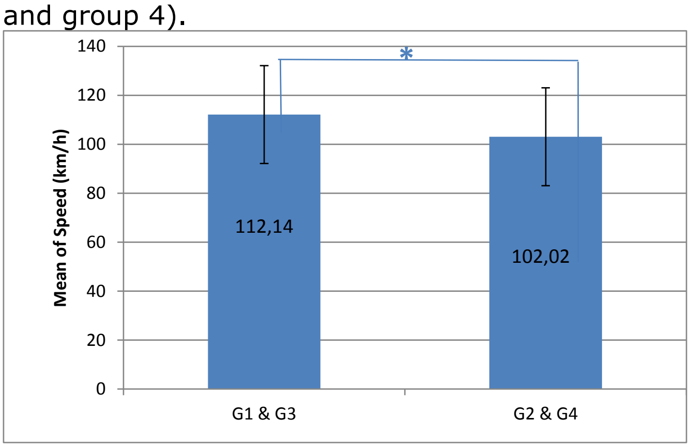

Fig. 4. Mean of speed (km/h)

Subjects not performing the dual task drove faster than others (see figure 4).

5.2.3. SD of lateral position (SDLP)

There was no interaction effect between group and lap variables (F(24,1754)=0.60, p=0.94). However, the group significantly influenced the SDLP (F(3, 1754)=156,39, p<0.01).

Table 3. Mean and SD of SDLP (m)

Groups	Means	SD
G1	0,83	0,52
G2	0,72	0,51
G3	0,84	0,47
G4	1,41	0,57

Over the 10 laps, the group 4 submitted to the dual task without traffic had the higher mean contrary to groups 1, 2, 3 (see table 3)

5.2.4. SD of Speed

There was no interaction effect between group and lap variables (F(24,1754)=0.60, p=0.93). However, the group significantly influenced the SD of speed (F(3, 1754)=41,018, p<0.01).

Table 4. Mean and SD for the SD of Speed (km/h)

Groups	Means	SD
G1	5,07	5,52
G2	7,01	4,74
G3	4,27	3,23
G4	4,58	3,30

Over the 10 laps, the group 2 submitted to the dual task with traffic had the higher mean contrary to groups 1, 3, 4 (see table4).

6. Discussion and conclusions

Results globally showed that whatever the experimental condition, no significant difference was clearly observed for the different sections of our presence questionnaire. Indeed, the vehicle traffic in the virtual world was not a positive predictor of the different sections of the MEC Spatial Presence Questionnaire. The dual task was not a negative predictor of these different sections either. Although the dual task didn’t have a strong effect on the subjective measures of presence, it affected the behavioral measures. As described in the literature [Wit29], low values in driving performance (SD of speed and SDLP) indicated a good steering control and a stable and consistent driving. Indeed, the SD of speed in traffic condition and the SDLP in no traffic condition were higher in dual task than in single task. Drivers submitted to the dual task without traffic drove in the middle of the road (the smallest mean lateral position), which could be interpreted as an efficient strategy but pretty inconsistent with the Highway Code. Similarly, participants submitted to the dual task in traffic condition have tried to reduce their speed as a compensatory strategy to deal with the dual task. Unfortunately, it appeared that they also failed to maintain a stable driving with a lack of speed control (the highest SD of speed). Thus, driving performance seemed to be globally impaired by the dual task. In conclusion, the main outcome was that behavioral measures revealed significant effects of the manipulated variables (traffic and dual task) on driving performance. These behavioral effects showed that participants took into account these variables. However, these effects were not confirmed by subjective reports. One explanation could be that, whatever the current experimental conditions, driving activity did not involve high-level, conscious, cognitive processes. Despite high scores reported through the MEC Spatial Presence Questionnaire, driving was probably more based on a set of procedures or routines. Our experimental conditions might have been insufficient to induce several distinct levels of attention, involvement and suspension of disbelief, leading to several distinct levels of presence (see figure 1). As developed by Schubert [Sch23], in the MEC model, internal factors (such as emotional arousal) are considered as key elements in the emergence of a sense of presence based on controlled attentional processes. Thus, high levels of self-reported presence (positively correlated with behavioral measures) might require to develop more challenging scenarios, in terms of controlled attention, cognitive involvement and more specifically in terms of emotions induced by the media. Actually, participants of driving simulation sessions are clearly aware that they are not exposed to any physical danger. According to Jamson [Jam12], the main problem to be solved is how simulated driving can reach out to them and engage them.

7. Acknowledgments

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