DOI: 10.2352/ISSN.2470-1173.2016.4.ERVR-412

Perceptual calibration in virtual reality applications

Daniel R. Mestre, Institute of Movement Sciences, Aix-Marseille University/CNRS, Marseilles, France

Abstract

As soon as "serious" conclusions (with respect to reality) have to be drawn from virtual reality experiences (training, virtual prototyping…), it is now more and more acknowledged that, besides display calibration and computer graphics issues, some attention has to be given to perceptual calibration, on the human side. This paper presents results from recent experiments that extend previous data on speed perception during driving simulation. They show 1) that the manipulation of the position of the rendering (virtual) camera strongly influences the drivers' speed perception, by transforming the optical flow pattern and 2) that this manipulation remains unnoticed by the driver and does not impact his/her attitude toward the simulation. They suggest that the position of the driver's viewpoint, with respect to the simulation screen, is of critical importance for the calibration of ecologically valid simulation systems. More generally they emphasize the fact that perceptual calibration is fundamental in "serious" virtual reality applications.

Introduction

It is commonly accepted (and partly true) that the information input to the typical driver is mainly visual [1]. The role of vision in driving is a long story, and, for instance, Burg [2] reported the results of a large-scale study, involving visual measurements in California drivers. To provide driver-licensing administrators with here-to-fore unavailable information on which to establish effective vision-screening procedures for driver license applicants, a number of visual performance, personal, and driving habit characteristics of 17,500 volunteer California driver license applicants were compared with their 3-year driving records (accidents and convictions). Of all the visual tests, dynamic visual acuity was most closely and consistently correlated with driving record, followed by static acuity, field of view, and glare recovery.

Dynamic visual acuity refers explicitly to the main visual input to the control of self-motion: the optic flow field [3, 4], being the optical transformations of the visual scene (the optic array in Gibson's terms), due to the motion of the observer's position (and point of view) in space [5]. There is now a solid convergence of data demonstrating that humans are able to use the optic flow field for effective and precise control of the direction of self-motion [6, 7].

However, if the control of our direction of travel appears to be precisely linked to the optic flow field, the perception of our speed of travel appears as more prone to biases and/or misjudgments, at least in absolute terms [8]. This question is of great importance, as soon as one is interested in drawing "safe" conclusions from virtual reality and simulation experimentations. Biased perception might lead to incorrect calibration of the sensorimotor loop, such that, in training conditions for instance, the skill transfer from driving simulation to real driving might be problematic and potentially leading to casualties. In this general context, it has been frequently observed that, in driving simulators, drivers tended to produce vehicles' speed much higher than the required speed [9]. This type of result argues for a tendency to underestimate self-speed in driving simulators, and that seems to be a more general problem during virtual reality exposure [10]. Mourant et al's [10] results also suggest that many parameters are involved in self-speed perception, such as the content of the visual scene or the visual field of view delivered by the driving simulator setup. More recently, researchers investigated the effect of a manipulation of the geometric field of view on self-speed estimation [11, 12]. In short, the actual field of view is related to the size of the display and the position of the driver's head (and viewpoint) relative to the display. The geometric field of view depends on the position of the virtual camera (used to render the virtual scene on the display). It can coincide with the driver's head position (this coincidence will be used later as a reference condition). But it can also be moved relative to the rendering display. Results from such manipulations are that the displacements of the virtual camera result in systematic distortions of the perceived speed of self-motion by the driver.

In the present studies, we aimed at reproducing and extending these results, with two further questions: 1) do these effects depend on the type of display setup? We compared a standard compact driving simulator to a Cave setup, in order to test for potential effects of the level of immersion on perceived speed; 2) do these manipulations affect the level of presence felt by the drivers [13] and/or induce some level of cybersickness [14]. The general objective of our work was to test whether manipulations of the geometric rendering of a virtual scene were a robust and safe way to manipulate speed perception in a driving simulator. In more applied way of thinking, we aimed at demonstrating that one has to pay attention to the relative positioning between the driver's position and the rendering camera, as a direct way to calibrate a vehicle's simulator.

Methodology

Apparatus

Participants drove on a driving simulator developed by OKTAL (www.oktal.com), running the SCANeR Studio ® software, under Microsoft® Windows 7 (figure 1). This fixed-base compact simulator is composed of a mockup, a seat, a steering wheel with force feedback, pedals and manual or automatic drive (it was used here in automatic mode). It enables full control of driving scenarios, real time interacting driving, visual and auditory feedback, and on-line recording of simulated trajectories.

We used this simulator in 2 display configurations. In a first configuration, the simulator was used in its native state. The virtual urban environment was projected on 3 screens, covering approximatively 120 degrees of the driver's visual field (see figure 1).

In a second configuration, we used the same simulator. However, the 3 screens (figure 1) were dismounted and the simulator was installed in the middle of our CAVE setup (figure 2). Thanks to the engineering team of CRVM (www.crvm.eu), the SCANeR software was connected to the rendering cluster and software of the CAVE. We thus achieved our objective, which was to vary ONLY the display setup between configurations 1 and 2. In particular, the frame rate was kept constant between both configurations (60 Hz). In all herein reported conditions, sound rendering was deactivated, as well as the speedometer, such that the driver would rely only on the visual rendering to perceive and regulate the simulated car's speed.

Figure 1. A view of the simulator in the first configuration, with 3 screens and a visual field on approximatively 120 degrees. The supplementary screen behind the steering wheel is used as a dashboard in the simulator's original setup and was not used in the experiment to mask the car's speed.

Figure 2. The simulator in the second configuration, installed in the CRVM's CAVE. This is a four sided setup, with a 10x10 inches floor and 3 vertical screens (10 x 13 inches), such that the whole driver's visual field was stimulated in that configuration.

Environment

We designed an urban environment (figures 1 and 2), The path along which the driver travelled was approximatively 400 meters long and was essentially straight (a slight curve was inserted such that the driver could not see all the way down to the end of the path).

Procedure

In this experiment and for both configurations, we used a psychophysical procedure. Within a single trial, the participant was first presented with a passive situation, in which s/he was "travelled" on the path at a constant speed of 50 km/h (about 30 mph, being the speed limit in urban zones in France). In fact, the vehicle accelerated to the defined speed, then crossed a "start" banner and stayed at this speed until it crossed a "finish" banner at which point it started to decelerate to stop. The participant was asked to pay attention to the start-to-finish zone. After that, for each trial, the car was brought (instantaneously) back to its original position and the participant was instructed to reach and keep the same speed (between the start and stop banners), while rendering variables were manipulated (see below).

At the end of the experimental session, in order to get the participants' psychological attitude toward the experimental setup, they add to fill (using a digital tablet) two questionnaires: First, the Simulator Sickness Questionnaire [15] was used to evaluate possible adverse effects of the exposure to the simulator (the whole experiment lasting almost 1 hour total).

Secondly the Igroup Presence Questionnaire [16] was administrated, to evaluate the degree of presence felt by the participants during the simulations, along three sub-scales (spatial presence, involvement and realism).

Manipulated variables

First, prior to the experiment itself, the participant was required to read a written instruction sheet, explaining the task and to give his/her written informed consent. S/he was asked afterwards to take seat in the simulator, to adjust the seat belt and to adopt a comfortable position, with the head on the head rest. S/he was instructed that s/he would have to keep this position (as much as possible) along the experimental session. Once that was done, the position of the head with respect to the ground and to the center of the front screen was measured. This position defined the reference position of the rendering (virtual) camera in the condition for which the virtual camera was exactly coincident with the participant's head. This reference position of the rendering camera was always used in the first part of a trial (passive travel at 50 km/h, see above, procedure).

In the second part of a given trial, the participant (never seeing the actual simulated car's speed on the dashboard), had to reproduce the reference speed, while the position of the rendering (virtual) camera was systematically manipulated. The manipulation was made on two dimensions, in height and depth (see figure 3).

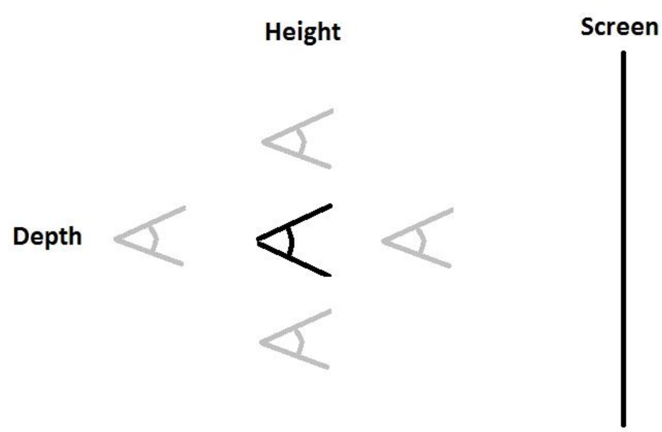

Figure 3. The reference condition is the center position (in black), for which the virtual camera and the driver's viewpoint coincide. 2 dimensions were manipulated: the virtual camera (in grey) could be moved in height (vertically) above and below the reference position. It could also be moved in depth, closer or farther to the frontal projection screen (not to scale).

DOI: 10.2352/ISSN.2470-1173.2016.4.ERVR-412

The virtual (rendering) camera was moved along the dimensions depicted in figure 3. In fact, in our conditions, for both configurations, we manipulated a group of cameras (3 in configuration1, 4 in configuration 2). The manipulated position thus refers to the common center point of the virtual cameras.

For the height manipulation, if the reference position is the center position (see figure 3) and noted 1, as the ratio between the position virtual camera(s) and the subject's head, we defined camera's height ratio of .7, .85, 1, 1.15 and 1.3. For instance, 1.3 corresponds to a position in height of the virtual camera that is 130% higher than the driver's head (with respect to the ground, both real and virtual). A value of .7 corresponds thus to a 30% lowering of the virtual camera. The same manipulation principle was applied to the depth dimension. The camera could be moved closer (than the driver's head) to the projection screen or away from it. Manipulated camera's depth ratios were the same as the height ratios (.7, .85, 1, 1.15 and 1.3).
Note that the neutral position of the virtual camera (1) appears in both dimensions. It was not repeated in the experimental trails. By crossing the two dimensions, this resulted in 9 conditions of the virtual camera's position. Each condition was repeated 6 times, resulting in 54 trials for each participant. Each trial (30 sec of automatic driving in the reference condition followed by 30 seconds of active driving with rendering manipulation) lasted around 1 minute, with inter-trial time. The whole experiment lasted around 1 hour, with optional resting periods (without the possibility of the participant to leave the seat, which would have biased the reference condition). Finally, the succession order of the trials was randomized between subjects, across conditions of camera's position and repetitions of a given condition.

Participants

In the first configuration with 3 frontal screens (which we will call from now on Experiment 1; see figure 1), 11 subjects (mean age: 25 years; sd = 2 years) voluntarily participated in the experiment after filling an informed consent form. They all were experienced drivers with a minimum driving license holding span of 3 years. Only active drivers, for the last 3 years, with normal or corrected to normal vision could participate. The experiment was conducted in accordance with the Declaration of Helsinki, after approval by the local ethics committee.
In the second configuration –CAVE- (Experiment 2, figure 2), 8 subjects (mean age: 25 years; sd = 6 years) took part in the experiment, with an identical inclusion protocol.

Results

Speed reproduction

The principal dependent variable that was analyzed was the speed produced by the subject in the second part of each trial. Remember that, in the first part of each trial, subjects saw a "film" of the trajectory, run at a constant speed of 50 km/h (they never actually saw a digital representation of this speed and they were not told the speed was 50 km/h). They were just told that they had to produce the same speed in the second part of each trial. Note also that the reference speed was always shown in the first part of the trial in order to prevent a possible drift in the subject's behavior along the experimental session. We used a repeated-measure analysis of variance on individual data, averaged over the 6 repetitions of a given camera condition. Independent variables were the camera position ratio, in depth and height (within-subject variable) and the configuration (3 screen simulator –exp1- or "in-cave" simulator –exp 2-) as a between subject variable.
Analysis of these data shows a highly significant effect of the virtual camera position. Considering first the camera depth ratio (figure 4), we can see that this ratio has a significant linear effect on the speed produced by the subjects ($F[4, 68] = 187.43$; $p<.00001$). In all cases reported here, linear regression coefficients are superior to .90. In other terms, if 1 is the reference camera's position (corresponding to what the subjects saw in the first part of each trial, when travelling at 50 km/h, with the rendering camera and the subject's head coincident), when this condition is reproduced in the second part of the trial, subjects reproduce, on average, a speed around 50 km/h. When the ratio is inferior to 1, when the virtual camera is closer to the simulator's screen, resulting in an increase in the optic flow speeds, the subjects produce a speed that is significantly inferior to 50 km/h (see figure 4). In other words, this indicates that subjects over-estimate their speed of travel, with respect to the reference speed. The exact opposite is true when the camera depth ratio is superior to 1. The virtual camera is farther away from the screen, the optic flow speed is reduced (as compared to the reference ratio of 1), subjects underestimate their speed and, as a result, produce travel speeds that are significantly higher that the reference speed.
This effect is observed for both configurations. However, we observe a significant interaction effect between the configuration and the camera ratio ($F[4, 68] = 44.92$; $p<.00001$). The effect (the slope of the curve) is much stronger for the 3 screen simulator than for the "in cave" simulator. We are left here with hypotheses which require further investigation. One possibility is that spatial presence is higher in the cave (see the evaluation of presence below), such that distortions of visual rendering would be more noticeable in the cave and/or optic flow distortions would be related to modifications in the perceived spatial scale of the environment. As a result the induced effect on perceived self-speed would be weaker. One question we cannot answer here is whether, in the same time, the absolute perception of speed is better in the cave (since there are contradictory results in this domain). Another possibility (also requiring further investigation) is that, in the cave, camera positioning in depth has less effect in peripheral vision. In this sense, it might be that, in a CAVE setup stimulating the whole visual field, manipulations of the virtual camera's position have a weaker effect, taking into account the fact that peripheral vision is highly involved in the perception of self-motion.

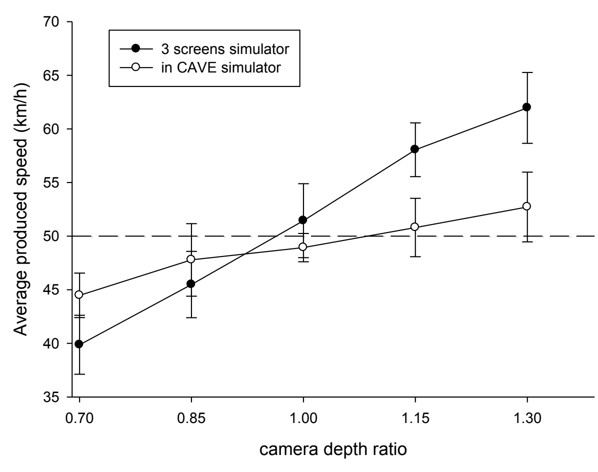

Figure 4. Average values of produced speed of travel (with standard deviations), as a function of camera depth ratios and configuration setup. Note that the effect is highly linear, stronger for the 3-screen simulator, than for the "in-cave" simulator. For a camera depth ratio of .7, produced speed reduction is around 20 % for the 3-screen simulator.

DOI: 10.2352/ISSN.2470-1173.2016.4.ERVR-412

The same basic effect is observed for the manipulation of the camera's position in height (figure 5). First, if you compare depth and height ratio manipulations (compare figure 4 and 5), the effect is weaker for the height ratio manipulation, as compared to the depth ratio manipulation (F[4, 68] = 6.69; p<.0002). This effect can be explained by the fact that the manipulation is depth impacts a much larger part of the optic flow field than the manipulation in depth (which mainly changes the "ground" part of the optic flow field.

Besides that, we observe here again a significant and linear effect of the camera height ratio (figure 5). There is here no significant interaction effect between camera height ratios and configuration, signifying that the effect is similar for the two configurations.

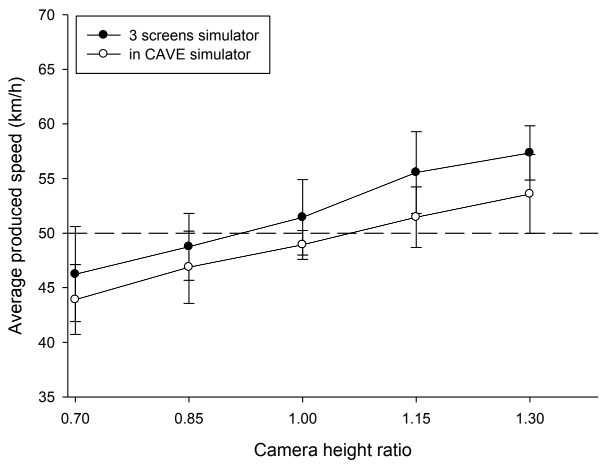

Figure 5. Average values of produced speed of travel (with standard deviation), as a function of camera height ratio and configuration setup. Note that the effect is highly linear, and similar for both configurations.

Questionnaires

Besides the evaluation of speed reproduction's performance, we tried to evaluate the participants' psychological attitude towards the simulator and the experimental manipulations, first in terms of the level of presence felt by the subjects when exposed to the simulator scenario, then in terms of potential adverse effects of virtual exposure (cybersickness).

IPQ

First, we used the Igroup Presence Questionnaire, developed by Schubert [16]. This questionnaire measures 3 components of presence: spatial presence (the feeling of being surrounded by the virtual environment); involvement (attentional focus on the virtual world) and realism (how real the VE was judged to be). There is also a "general" component ("In the computer generated world I had a sense of being there").

In all cases, subjects filled the questionnaire after completion of the experimental session. An analysis of variance was conducted on individual scores for the four questionnaire categories, as a function of configurations (named here exp 1: 3-screen simulator and exp 2: in cave simulator).

We found a significant effect the questionnaire categories (figure 6). Involvement and realism gave significantly lower scores than spatial and general components (F[3, 51] = 8.6469; p<.0001). Looking at figure 6, you can mention that there is a lot of dispersion in the scores and that, on a -3 (worse) to +3 (better) scale, the values are rather "average" (close to zero). This suggests that, in such simulation scenarios (even within a CAVE immersive system), the general level of presence is low (there is a non-significant tendency for higher scores of general and spatial presence in a CAVE –exp 2). Secondly, the "worst" scores are for involvement and realism. Here again, being in a CAVE does not change the general response profiles. There is certainly progress to be made here, in terms of "engaging" driving scenarios, for instance. In other words, our experiment might have been boring for the participants and one may rightfully ask whether increasing presence might change perceptual evaluations (of self-speed in our case). Coming back to that, we mentioned, discussing speed production previously, that the difference in performance between both configurations might be related to differential levels of presence. This does not appear to be the case, leaving us with the suggestion that the observed effects on speed production are merely perceptual, based on manipulated sensorial inputs (optic flow pattern here).

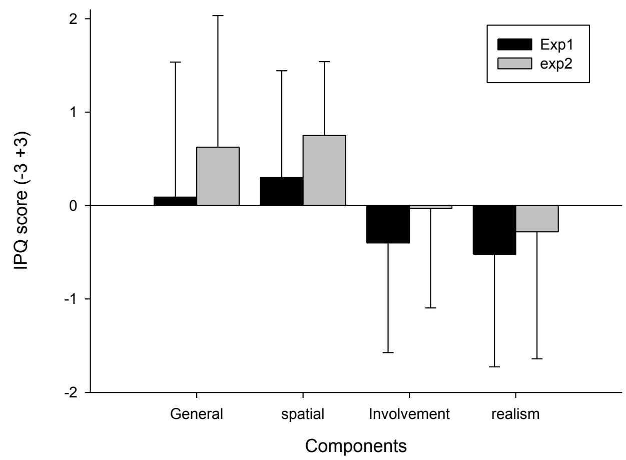

Figure 6.Average values (with standard deviations) of IPQ scores for the three components of the questionnaire and the general component, between exp 1 (3-screen simulator) and exp 2 (in cave simulator).

SSQ

Finally, we tested whether the camera's positioning manipulations might have affected cybersickness symptoms, as suggested by [14]. We thus used the "classical" Simulator Sickness Questionnaire, developed by [15].
This questionnaire addresses 3 factors (or sub-scales) of discomfort in simulators: nausea (questioning "physiological" symptoms, such as salivation, sweating….); oculomotor symptoms (such as fatigue, difficulty focusing…) and disorientation (vertigo, dizziness…). There is also a total score, derived from these sub-scales. One advantage of this questionnaire is the fact that is has been validated on more than 1000 subjects.
The main effect that was observed here is a significant difference between the scores of the 3 factors of the SSQ (figure 7). The oculomotor factor always gives higher scores than the nausea and disorientation factors (p<.0001; using post-doc analyses). There is a non-significant tendency of the CAVE condition (exp 2) to give rise to higher scores, as compared to the 3 screen simulator (exp 1). What

can be concluded from that analysis is that significant scores of cybersickness are observed in both configurations. However, these scores (on a scale with a maximum value of about 100) are of moderate intensity (see figure 7). Moreover, oculomotor fatigue is mainly observed, taking into account the fact that the experiment lasted for about 1 hour, requiring much concentration (staring at the screens in particular).

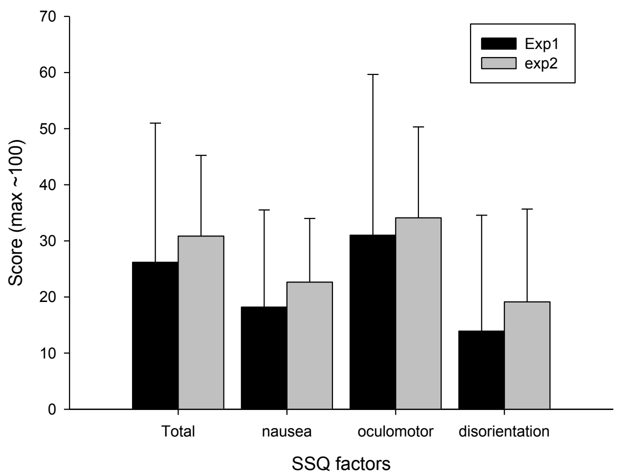

Figure 7. Average values (with standard deviations) of SSQ scores for the three factors of the questionnaire and the total component, between exp 1 (3-screen simulator) and exp 2 (in cave simulator).

Conclusions

This experiment extended previous results [11, 12]. Varying the rendering setup (basic simulator versus CAVE immersive display) does not change the basic results from previous studies. Altering the geometric visual rendering of the virtual environment systematically affects the driver's perception of his/her speed of travel. The effect is clearly linked to the optic flow pattern. The fact that the strength of the effect can be modulated by the rendering setup is also accounted for by a rather pure sensorial effect. Furthermore, the result showing that the effect of a manipulation in depth of the rendering camera is weaker in a cave can also be related to the geometry of the optic flow in central and peripheral vision.

The investigation of the participants' attitude toward the rendering context, using presence and cybersickness questionnaires, confirmed the fact that the virtual camera manipulations engender a pure perceptual effect. Obviously, the questionnaires also revealed other aspects of the simulation scenarios that need to be improved (poor judged realism, oculomotor fatigue…).

However, besides these effects, the point we want to conclude on is the fact that these systematic effects of the rendering camera's positioning argue for the need for a close attention to the spatial relationships between the operator's head and the rendering display in a vehicle's simulator.

The first conclusion could be that it is of crucial importance to place the operator at the correct position, which is the rendering camera position. It might be that previous results reporting incorrect perception of speed are (at least partly) due to insufficient attention to this coincidence. This obviously has great importance in terms of the validity of training (as well as research) simulators.

The second conclusion might be that, when this coincidence (for technical reasons for instance) is not possible, one might want to evaluate the speed perceptual bias and manipulate the rendering camera position to reach a correct perception.
Finally, when the perception of speed is still incorrect for reasons besides the correct position of the operator in the simulator (luminance, contrast, spatio-temporal resolution…), rendering camera positioning might also be a way to restore a correct perception.

These points and suggestions require further investigation (notably in terms of perceptual biases in the perception of speed and their causes). Finally, the linear relationships found between the rendering camera positioning and speed perception are empirical, and have been observed in limited conditions (one reference speed for instance and a psychophysical experimental procedure). Studying more complex and ecological tasks and scenarios would be essential to obtain a more general model of speed perception in virtual environments.

Acknowledgements

This research was supported by BPI France, under grant number O14734-413096 (SIMVIR project: 3D geo-specific digital models for simulator studies and driver training). The author wishes to thank the team at CRVM (Pierre Mallet, Jean-Marie Pergandi, Vincent Perrot and Gregory Smialek) for their assistance in the design and execution of the experimental work.

References

[1] B.L. Hills, "Vision, visibility and driving," Perception, 9, 2, pp.183-216, 1980

[2] A. Burg, "Vision and driving: A summary of research findings," Highway Research Record, 216, pp. 1-12, 1968

[3] J.J. Gibson, The perception of the visual world. Boston, Massachusetts: Houghton Mifflin, 1950.

[4] J.J. Gibson, The ecological approach to visual perception, Boston: Houghton Mifflin, 1979.

[5] D.R. Mestre, "Visual perception of self-motion," In L. Proteau & D. Elliott (Eds.), Vision and Motor Control (Advances in Psychology Series), Amsterdam North-Holland. pp 421-440, 1992.

[6] W.H. Warren, D.R. Mestre, A.W. Blackwell & M. Morris, "Perception of circular heading from optical flow," Journal of Experimental Psychology Human Perception and Performance, 17, 1, pp. 28-43, 1991.

[7] M. Lappe, F. Bremmer & A.V. van den Berg, "Perception of self-motion from visual flow. Trends in Cognitive Sciences, 3, 9, pp. 329-336, 1999.

[8] A. Kemeny & F. Panerai, "Evaluating perception in driving simulation experiments," Trends in Cognitive Science, 7, 1, pp. 31-37, 2003.

[9] T. Banton, J. Stefanucci, F. Durgin, A. Fass & D. Proffitt, "The perception of walking speed in a virtual environment," Presence: Teleoperators and Virtual Environments, 14, 4, pp. 394-406, 2005.

DOI: 10.2352/ISSN.2470-1173.2016.4.ERVR-412

[10] R.R. Mourant, N. Ahmad, B.K. Jaeger & Y. Lin, "Optic flow and geometric field of view in a driving simulator display," Displays , 28, pp. 145-149, 2007

[11] C. Diels, A.M. Parkes, "Geometric Field of View manipulations Affect Perceived Speed in Driving Simulators," Advances in Transportation Studies, B 22, pp. 53-64, 2010.

[12] F. Colombet, D. Paillot, F. Mérienne & A. Kemeny, "Visual Scale factor for speed perception," Journal of Computing and Information Science in Engineering, 11, 4, 2011.

[13] Mestre, D.R. and Vercher, J.L., "Immersion and Presence," In Ph. Fuchs, G. Moreau & P. Guitton (Eds.), Virtual Reality: Concepts and technologies, London: CRC Press, pp. 93-102, 2011.

[14] M.H. Draper, E.S. Viire, T.A. Furness & V.J. Gawron, "Effects of Image Scale and System Time Delay on Simulator Sickness within Head-Coupled Virtual Environments," Human factors, 43, 1, pp. 129-146, 2001.

[15] R.S. Kennedy, N.E. Lane, K.S. Berbaum & M.G. Lilienthal, "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness," The International Journal of Aviation Psychology, 3, 3, pp. 203-220, 1993.

[16] T. Schubert, " The sense of presence in virtual environments: A three-component scale measuring spatial presence, involvement, and realness," Zeitschrift für Medienpsychologie, 15, 2, pp. 69-71, 2004.

Author Biography

Daniel R. Mestre is a senior researcher in the Institute of Movement Sciences (www.ism.univ-amu.fr) in Marseilles, France. He is Head of the Mediterranean Virtual Reality Center (www.crvm.eu) and a founding member of the Association for Virtual Reality (www.af-rv.fr). His major research interests concern active visual motion perception, psychophysical and neuropsychological approaches to sensory information processing. Virtual reality is used as an experimental tool to understand our presence to the world, in both fundamental and applied domains.