Article:

Jamson, SL and Jamson, AH (2010) The validity of a low-cost simulator for the assessment of the effects of in-vehicle information systems. Safety Science, 48 (10). pp. 1477-1483. ISSN 0925-7535

https://doi.org/10.1016/j.ssci.2010.07.008

The validity of a low cost simulator for the assessment of the effects of in-vehicle information systems

Samantha L. Jamson
and
Hamish Jamson

Institute for Transport Studies,
University of Leeds,
Leeds, LS2 9JT,
UK
Tel: +44 (0)113 3436606
Fax: +44 (0)113 3435334

Corresponding Author:

Samantha L. Jamson, Institute for Transport Studies,
University of Leeds, Leeds, LS2 9JT, UK
S.L.Jamson@its.leeds.ac.uk
Tel: +44 (0)113 3436606
Fax: +44 (0)113 3435334

Abstract

This study explored the validity of using a low-cost simulator for the assessment of driver distraction arising from the use of an in-vehicle information system. Eighteen participants drove on a rural road whilst carrying out distractor tasks of various levels of difficulty, in both a low-cost simulator (with gaming console steering wheel and pedals with single monitor display) and a medium-cost one (fixed-base, complete vehicle cab, wrap-around visuals). The distractor tasks were presented at identical locations in each of the drives and an identical suite of driver performance and subjective rating measures were elicited to allow a robust comparison between the two simulator environments. As expected, there was a reduction in mean speed when drivers were completing the distraction tasks and this effect was observed in both simulators. However, drivers spent more time at shorter headways in the low-cost version and demonstrated more erratic steering behaviour in the low-cost version. This could be due to a reduced peripheral view and inferior kinaesthetic feedback through the driver controls, but low-cost simulators could play a significant role in the early stages of design and evaluation of in-vehicle information systems.

Keywords: Low cost simulator, distraction, evaluation, in-vehicle information systems

1. Introduction

Simulator designers typically strive to reproduce high quality visual, auditory and kinaesthetic cues within their facilities in order to artificially recreate a realistic driving environment. A simulator's technical characteristics have some bearing on its validity in a number of ways. First, there is the issue of motivation. Participants are clearly aware that they are not exposed to any physical danger whilst driving, but to what extent does the simulated drive absorb them? How real does the simulated driving experience feel to them – is the simulator "emotionally" valid? Next, there is the issue of "physical" validity: how does the simulator's dynamic behaviour match that of the vehicle it is imitating – do similar applications of the driver controls induce the same vehicle performance as one would expect in the real world? Thirdly, there is "face" validity: how is the simulator perceived in terms of its look and feel – do the vehicle interior and controls resemble those in the real vehicle? Fourthly, "perceptual" validity must be considered. Do drivers acquire the appropriate ocular, auditory and proprioceptive cues in order to make accurate estimations of distance, speed and acceleration? Finally, and undoubtedly the most important in a research environment, "behavioural" validity – does a driver's perception of the environment lead to comparable vehicle control under both simulated and natural conditions? These issues of simulator validity have led to a number of studies that have attempted to validate these tools against real-world driving behaviour (e.g. Carsten et al., 1997; Carter and Laya, 1998; Reed and Green, 1999).

Simulator studies enjoy many benefits over real world studies, the main one being their versatility. They can be easily and economically configured to evaluate a variety of human factors research problems and controllable and repeatable virtual scenarios can be created to exactly match the requirement of a particular investigation (Kaptein, Theeuwes and Van der Horst, 1996). Environmental conditions can be manipulated such as time of day (e.g. De Valck et al., 2006), weather conditions (e.g. Broughton et al., 2007) and state of the road surface (e.g. Peltola, 2002). The parameters of the driven vehicle can be altered, such as suspension design (e.g. Sayers and Han, 1996), tyre construction (e.g. Pacejka and Besselink, 1997) and steering characteristics (e.g. Jamson et al., in press). Novel road marking schemes (e.g. Steyvers and De Waard, 2000), methods of signage (e.g. Charlton, 2006) and road infrastructure (e.g. Shechtman, et al. 2007) can be modelled virtually and evaluated without the logistic and financial implications of modifying large areas of public road-space. Furthermore, simulators have ethical advantages over real world investigations by providing an inherently safe environment for drivers. This makes simulators particularly useful for studies into fatigue, (e.g. Philip et al., 2005.) and medical impairment (e.g. Anderson et al., 2007).

However, research simulators have their disadvantages. Whatever the development budget, a simulator's validity is always arguable since the complexity of the real world can never be replicated in its entirety. As a method of data collection, the simulator is commonly criticized for its lack of ecological validity (Neale & Liebert, 1986) since those social and motivational pressures common to everyday driving are removed. At the tactical level of driving (Michon, 1985), the evaluation of vehicle speed and the estimation of inter-vehicle distance is an essential skill in safe and controlled driving and manoeuvres such as overtaking and collision avoidance require these abilities. In a driving simulator, these skills require the accurate representation of self-motion from both optic flow and egocentric direction (Gogel and Tietz, 1979). Optic flow cannot give information about either absolute speed or distance but it can be used to compare relative spatial intervals, central to the accurate estimation of time-to-contact (Lee, 1980). Studies into speed perception have shown that observers tend to underestimate their velocity in simulated environments (Howarth, 1998; Groeger et al., 1997). Many driver-centred validation studies have reported higher observed speeds and speed variation in simulated compared to natural conditions (Alicandri, Roberts and Walker, 1986; Riemersma, Van der Horst and Hoekstra, 1990; Duncan, 1995; Blana, 1999). These judgements of speed are also sensitive to image contrast (Blakemore and Snowdon, 1999), the amount of texture (Blakemore and Snowdon, 2000), projector brightness (Takeuchi and De, 2000) and the overall field of view (Jamson, 2000). Distance estimation is also based on a number of reliable cues, such as optic flow (Bremmer and Lappe, 1999), disparity (Howard and Rogers, 1995) and motion parallax (Rogers and Graham, 1979). Recent studies using driving simulators have shown that the central nervous system is able to infer absolute distance less efficiently in a virtual environment than it does under natural conditions. This leads to an under-estimation of distance (Groeger et al.,1997; Boer et al., 2001).

A further issue with driving simulators, especially those with large motion systems, is that they can be highly expensive to set up. Simulators were originally developed to train pilots, but it is not economically feasible to use high-cost simulators for the training of drivers – hence some would argue that high-cost simulators have been developed without solid reasoning. Finally, some people can develop simulator sickness when driving, with symptoms lasting for several hours afterwards (LaViola, 2000). A number of researchers have highlighted ways in which simulator sickness can be minimised; Duh et al. (2004) suggest providing individuals with rest frames (stationary objects) within the visual scene allows them to determine which other objects in the environment are stationary and which are in motion. Those who have difficulty identifying a rest frame in a virtual environment are more likely to experience cybersickness. Rizzo et al. (2003) suggests that braking manoeuvres should be minimised in driving simulator studies, particularly in the familiarisation period.

All of these factors must be taken into consideration by a researcher when considering the type of environment in which to undertake a study. This decision may also be influenced by financial and time restraints, particularly during pilot studies, or when the behavioural effects are not fully understood. In such situations, it may be beneficial to use a low-cost simulator to carry out a small-scale study. This will also allow the development of a more sophisticated experiment, based on the pilot results. The researcher needs to be relatively confident, however, that the low-cost version provides an adequate research environment. This is the purpose of the study reported here – to investigate whether the results obtained using a cut-down version of a driving simulator can be compared with those obtained in the full-scale version. A number of examples of low-cost driving simulators exist, allowing basic driving research to be undertaken in a much less immersive environment. However, there have been only limited attempts to investigate the trade-off between set-up cost and driving simulator validity. Jamson and Mouta, (2004) suggest that a "law of diminishing returns" applies: whilst investment in a medium-cost simulator may provide the researcher with a more valid tool than a low-cost one, depending on the study in question, the additional investment might not be justified since driver behaviour may not differ significantly between the two simulators.

The European project, HASTE, provided us with the opportunity to study this in the context of driver distraction and performance. It is well established that distraction impairs driving performance. For example, research studies have highlighted the consequences of using a mobile phone whilst driving (e.g. McKnight and McKnight, 1993; Strayer, et al., 2003) and have been instrumental in influencing current legislation. The safety evaluation of In-Vehicle Information Systems (IVIS) is less advanced, with new products being continuously marketed. It has been argued (Carsten and Brookhuis, 2005) that the safety evaluation of products such as IVIS require more than the use of a checklist; however the use of a full-scale driving simulator may not be a practical option, particularly in the early design phases of the system. There is merit in having a tool that is somewhere between the two, is easy to administer and provides a degree of basic driving safety data. This tool would have to be a reliable predictor of behaviour and, as such, be able to present a range of driving scenarios and traffic conditions. One way of achieving this is to simply scale down a driving simulator to its most essential components and provide manufacturers or researchers with a tool that is mobile, yet retains a certain amount of sophistication and face validity. This study explored the coherence of results obtained in two experimental settings (low-cost and medium-cost driving simulator) in both baseline and distracting driving conditions. A variety of driving performance and subjective measures were evaluated across a range of distraction task difficulties.

2. Method

This repeated measures study allowed the comparison of driving performance in two different simulation environments. As well as collecting data relating to “baseline” driving, distraction tasks were introduced to increase driver workload and provide the opportunity of comparing the simulators in safety-critical scenarios.

2.1. Facilities

This study utilised two facilities: the Leeds Driving Simulator and the Leeds LabSim. The Driving Simulator was based on a complete Rover 216GTi with all of its basic controls and dashboard instrumentation still fully operational (Figure 1). On a 2.5m radius, cylindrical screen in front of the driver, a real-time, fully textured and anti-aliased, 3-D graphical scene of the virtual world was projected. This scene was generated by a SGI Onyx2 Infinite Reality2 graphical workstation. The projection system consisted of five forward channels, the front three at a resolution of 1280x1024 pixels. The images were edge-blended to provide a near seamless total image, and along with two peripheral channels (640x480 each), the total horizontal field of view was 230°. A rear view (60°) was back projected onto a screen behind the car to provide an image seen through the vehicle's rear view and wing mirrors.

Realistic sounds of engine and other noises were generated by a sound sampler and two speakers mounted close to each forward road wheel. Although the simulator was fixed-base, feedback was given by steering torques and speeds at the steering wheel. Data were collected at 60Hz and included information of the behaviour of the driver (i.e. driver controls), that of the car (position, speed, accelerations etc.) and other autonomous vehicles in the scene (e.g. identity, position and speed).

LabSim was a low cost alternative to the full-scale driving simulator, running the same software, but with less immersive driver controls and image generation. The driver sat at a desk accommodating a Logitech Momo force-feedback steering wheel and pedals (accelerator and brake only). A real-time, fully textured and anti-aliased, 3-D graphical scene of the virtual world was displayed on an Acer 17” flat-panel display in front of the driver. The display was a single

1280x1024 channel with a horizontal field of view of 50° and a vertical field of view of 39°. It was generated by a dual processor, 3.2GHz PC hosting an nVidia FX3000G graphics card. This PC was connected via Ethernet to a Pentium 3 (CPU speed 700MHz) running the vehicle dynamics model at around 1.0KHz. To minimise latency, the driver controls were connected to this machine. The visual display update and data collection rates were 60Hz.

Figure 1 The Leeds driving simulator (left) and the Leeds LabSim (right)

2.2. Participants

Eighteen drivers were recruited for the study, of which nine were male (mean age 32 years) and nine were females (mean age 30 years). The age range was 25-50 years and on average, participants had held their driving licence for 15 years, had a minimum total driving experience of 10,000 km and had held their driving license for a minimum of 5 years. All participants were non-professional drivers and were recompensed for their time.

2.3. Experimental design

As the main aim of this study was to compare one testing environment against another, a within-subjects experimental design was employed to minimise systematic error. The two Simulator Types were included as a fixed factor (LabSim or Driving Simulator). In addition, there were two levels of Road Type (straight and curved) and nine levels of IVIS Task Type (including one baseline). Univariate Analysis of Variance (ANOVA) was used with a 5% level of significance and main and interaction effects of the three factors (Simulator, Road, Task) were studied.

The order in which participants drove the two simulators was randomised with nine participants using LabSim first and nine using it second. On both occasions, participants were required to complete the eight tasks detailed in Table 1. These IVIS tasks were provided by a PDA, positioned in its cradle. The cradle was fixed to the dashboard in the driving simulator or to the table adjacent to LabSim. The PDA had a colour touch display and data entry was made either by a stylus or by hardware keys. Data were mainly presented as visual information via icons and text.

Table 1 – Task descriptions (ranked by average task completion time)

Task no.	Task description	Main output modality	Manual effort
1	Check and report on visual information	Visual	None
2	Read a list of directions	Visual	None
3	Close the navigation program and re-open	Visual-Manual	Low
4	Change settings from large to small and back to large keys	Visual-Manual	Medium
5	Set destination using directory	Visual-Manual	Medium/High
6	Set destination using data entry	Visual-Manual	High
7	Zoom in to 10 meters, out to 10 km and back to 100 meters	Visual-Manual	Low/Medium
8	Change settings for route options	Visual-Manual	Medium/High

In terms of Road Type, the straight and curved sections were both 864m in length. The curved section was made up of 18 curved segments making a double s-shaped bend. Curves varied left and right and their radius fluctuated between 510m and 750m. This gentle curving scenario required some negotiation by the driver and driver workload was considered to be higher than on a straight section.

2.4. Driving scenarios

A single-carriageway rural road (96 km/h speed limit) was modelled, to incorporate the straight and curved test sections. These sections allowed for up to 90 seconds of driving performance to be measured (based on a speed of 96km/h). This was found, in piloting, to be sufficient time in which to complete the most difficult of the tasks. Filler sections were included to allow participants a period of rest between tasks. Test sections were also included where no IVIS interaction was required to allow for baseline data collection.

A lead vehicle was present throughout the whole drive; its speed was dependent on individual participant's preferred driving speed. To achieve this, the first section of the virtual drive included both a straight and curved section in which no lead vehicle was present. This allowed the measurement of "free speed" choice for each individual driver, measured separately on both straight and curved sections. The lead car travelled at a *driver-dependent speed* calculated as either:

Each driver's "free speed" minus 10%, or
Speed limit of the road (96km/h) minus 10%

The minimum of these two values was used for the lead car speed choice, so that the participants were, for the majority of the drive, in a car following situation. At the end of the free-speed sections, there was an intersection to allow for the introduction of the lead vehicle and around 1km of road to allow the lead vehicle to reach its driver-dependant speed. The width of the road was 7.3 metres made up of two carriageways of 3.65 metres each.

2.5. Measures

The dependent measures covered the whole spectrum of driving behaviour as one of the aims of the study was to establish whether certain driver measures were more sensitive to the type of driving environment. The dependent measures were grouped as:

- Subjective ratings
- IVIS task completion time
- Longitudinal vehicle control (speed and headway)
- Lateral vehicle control (steering)

2.6. Procedure

All participants were provided with written instructions and completed a consent form. They then underwent intensive training with the IVIS to ensure they were fully familiarised with the types of task they would be required to undertake in the experiment. They were then allowed a familiarisation period in the simulator (or LabSim) and then given the opportunity to practice the tasks whilst driving. Once participants felt confident they were able to perform the tasks, they completed the experimental drive. Following this, a rest period was allowed before practising in the other driving environment. Once this practice was completed, they undertook the remaining experimental drive. Driving data were collected on the two experimental drives and participants were asked to provide a verbal subjective rating of their driving performance on a scale of 1 to 10, following completion of the IVIS tasks.

3. Results

For the purpose of presenting the results, a subjective difficulty rating of each of the tasks was made by the experimenters. This grouped the tasks into those which were purely visual and short in duration (Tasks 1 and 2), those which also involved some manual operations (Tasks 3 and 7), and those which required a high degree of both (Tasks 4,5,6 and 8). This grouping is used in the presentation of the results only, and was not used to categorise the task in any statistical sense.

3.1. Task completion time

The time taken to complete each of the tasks varied widely between tasks and between road types. Main effects were noted for both the factors of Task Type [F(7,119)=174.75; p<0.01] and Road Type [F(1,17)=11.72; p<0.01] but the absence of an interaction between these two factors indicates that the tasks took similar amounts of time to complete, regardless of the Road Type (see Figure 2).

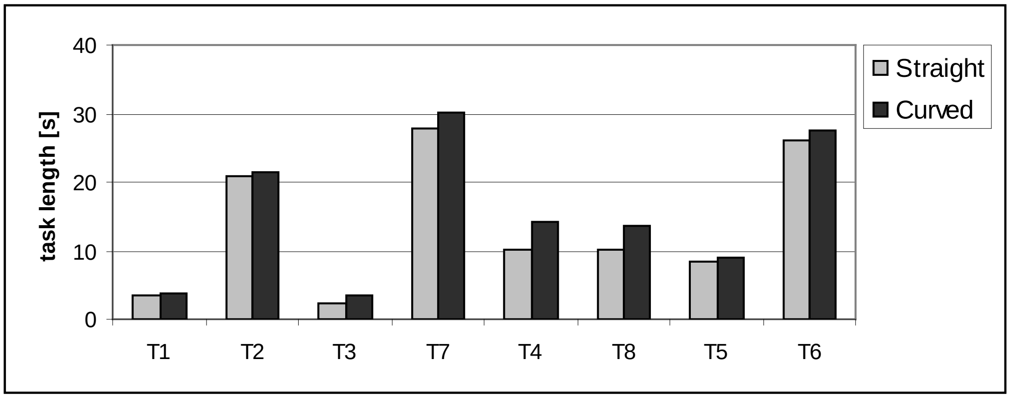

Figure 2 – Mean task completion time by Road Type

There were no main or interaction effects of Simulator Type, suggesting that drivers took comparable amounts of time to complete the task, regardless of whether they were using the Driving Simulator or the LabSim.

3.2. Self reported driving performance

With regards to the Simulator Type, drivers reported that their performance was significantly better in the Driving Simulator (mean = 5.9) compared to in the LabSim (mean = 5.4), [F(1,17)=6.35; p<0.05]. There were no significant interaction effects with either Task or Road Type (see Figure 3).

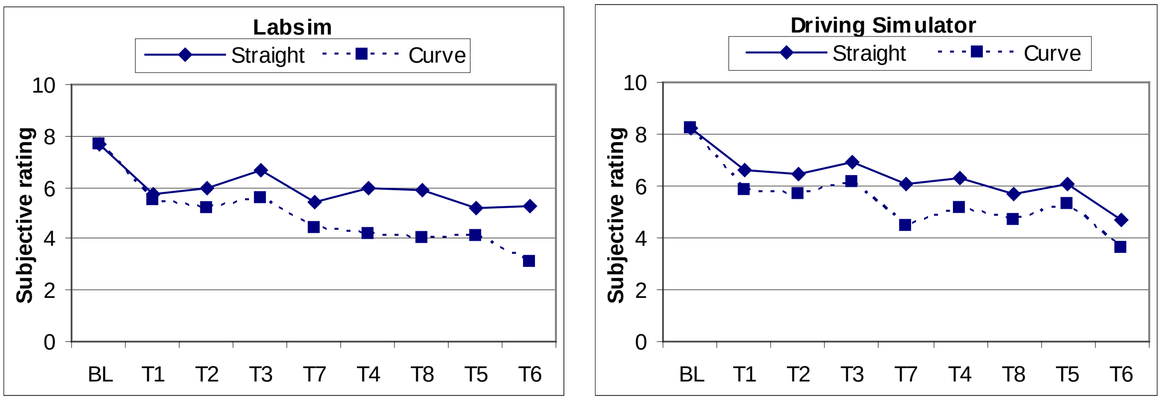

Figure 3 – Mean subjective ratings by Simulator Type (BL= Baseline, T=Task)

A significant main effect of Task Type on subjective ratings was found [F(8,136)=41.47; p<0.01], whereby subjective ratings decreased as the complexity of the tasks increased, and ratings for all eight tasks were significantly poorer compared to baseline driving (p<.001). There was also a significant main effect of Road Type [F(1,17)=69.01; p<0.01], with average ratings being higher on straights (mean=6.1) than on curves (mean=5.1). This main effect of Road Type was accompanied by a significant interaction with Task Type [F(8,425)=5.52 p<0.01], such that drivers reported a worsening of their driving performance on curves, compared to when driving on straights, for some tasks. This particularly applied to those tasks that, not surprisingly, had a high manual component.

3.3. Longitudinal control

There was no main effect of Simulator Type, indicating that drivers' speed choice was similar in the Driving Simulator and the LabSim and there were no interactions with Road or Task

Type. There was found to be a main effect of Task Type [F(8,136)=12.11; p<0.01] with the completion of the tasks resulting in a significant speed reduction compared to baseline driving, for all tasks (p<.01). Mean speed reduced by approximately 3km/h for the easier tasks (e.g. T1) and 6 km/h for the harder visual/manual task (e.g. T8), see Figure 4. A main effect of Road Type, [F(1,17)=6.2; p<0.05], indicated that overall, drivers travelled slower on the curves (mean =77 km/h) compared to the straights (mean=79km/h) and the absence of an interaction indicates that drivers reduced their speed in a similar fashion when performing the tasks, regardless of the Road Type.

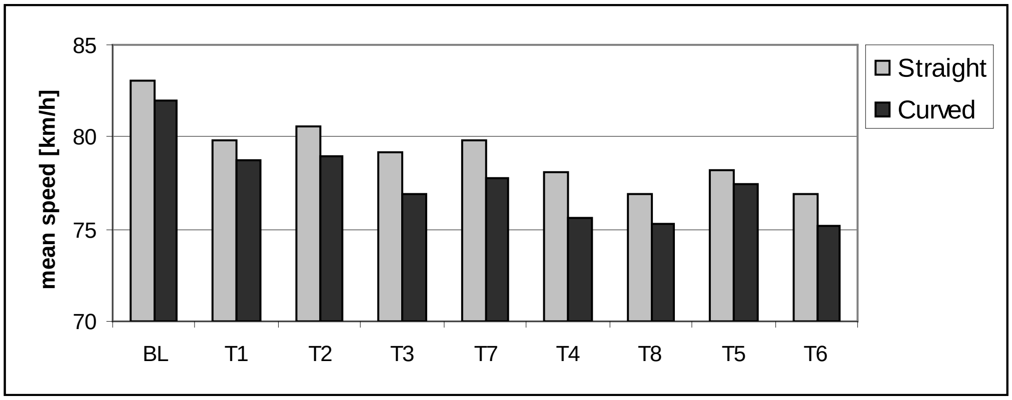

Figure 4 – Mean speed by Road Type (BL= Baseline, T=Task)

However, not all drivers reduced their speed whilst performing a task; some increased their speed, Table 2. Across all tasks and baseline periods, the majority of drivers increased or decreased their speed only slightly (less than 5%). When analysed separately, by task, it can be seen that Task 6 caused one third of drivers to decrease their speed, whilst Task 7 caused the same proportion drivers to increase their speed. These speed increases and reductions were stable between the two Simulator Types

Table 2 – Percentage of drivers who increased and decreased their speed during task completion

	% drivers who decreased speed	% drivers who increased speed
Baseline	12.50%	16.67%

Task 1	9.72%	25.00%
Task 2	12.50%	23.61%
Task 3	8.33%	13.89%
Task 7	12.50%	36.11%
Task 4	23.61%	30.56%
Task 8	15.28%	8.33%
Task 5	13.89%	20.83%
Task 6	33.33%	18.06%

These reductions in speed were coupled with significant increases in mean time headway to the vehicle in front, again with no associated main effect of Simulator Type.

There was a difference, however, between the amount of time drivers spent at short headways in the two simulators. Drivers were more inclined to spend longer periods of time at shorter headways (0-2 seconds) in the LabSim, [F(1,17)=6.39; p<0.01]. Figure 5 shows the amount of time drivers spent at these short headways whilst they completed the tasks. Even in the baseline driving sections, it appears that drivers were more inclined to travel closer to the vehicle in front.

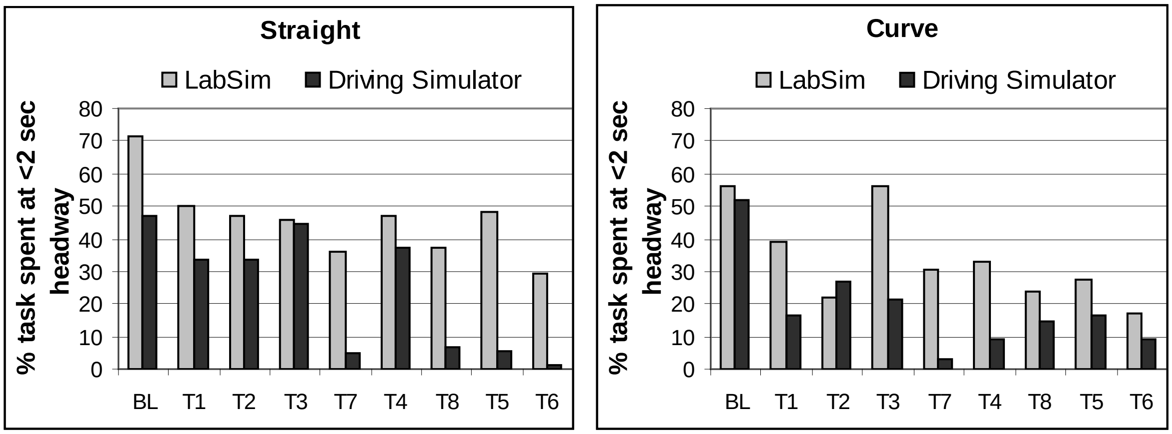

Figure 5 – Critical short headways by Simulator Type (BL= Baseline, T=Task)

3.4. *Lateral control*

Mean lateral position only differed for the factors of Road Type [F(1,17)=349.48; p<0.01] and Task Type [F(8,136)=2.28; p<0.05], with no difference between the two simulators. Changes in lateral position were also examined, although care has to be taken when analysing the variance in lateral position as this was dependent on task length. Main effects of Road Type [F(1,17)=82.07; p<0.01 and Task Type [F(8,136)=4.11; p<0.01] were found. Except for Tasks 2, 6 and 7, lateral position variation decreased during task completion.

A main effect of Simulator Type was found with more lateral deviation in the LabSim than in the Driving Simulator [F(1,17)=6.01; p<0.01]. A three way interaction between Simulator, Road and Task Type [F(8,425)=3.09; p<0.01] demonstrates that in LabSim, drivers deviated more in their lane in the curved sections of road when completing tasks with a high manual component (Tasks 5,8 and 6), Figure 6.

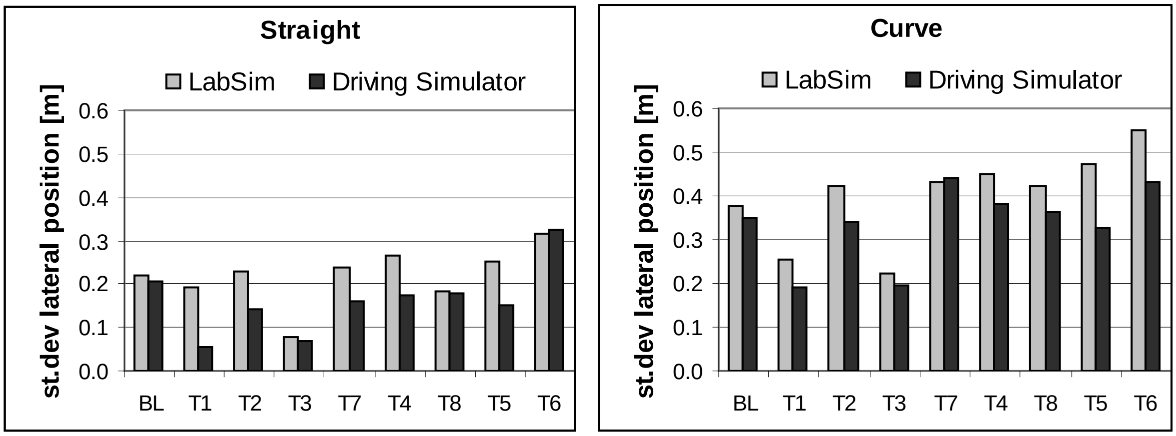

Figure 6 – Variation in lateral position by Simulator Type (BL= Baseline, T=Task)

Caution needs to be exercised when analysing variation in lateral position, due to the variation in task lengths. Therefore further analysis was undertaken using the high frequency component of steering. This is calculated as a ratio between steering inputs in the 0.3-0.6Hz range and all other steering inputs. The 0.3-0.6Hz range was identified by McDonald and Hoffman (1980) as reflecting steering corrections and a higher ratio thus means that more of these are being used by the driver to the control the vehicle. The analysis showed a main effect of Simulator Type [F(1,17)=18.85; p<0.01] with more corrections apparent in the Labsim.

4. Discussion

The main objective of this study was to make comparisons between data derived from a low-cost driving simulator and that from a full-scale one. Using distraction tasks this study collected identical behavioural parameters to establish if designers of in-vehicle systems could use a low-cost simulator to evaluate their products. This was achieved by using the same group of drivers, carrying out identical tasks in both environments, on identical pieces of simulated road.

The face validity of the distraction tasks was established whereby the completion of the IVIS tasks was associated with changes in driving behaviour: drivers were able to perceive these changes in behaviour in their self-reports and the completion of the tasks was coupled with a reduction in speed. This reduction in speed was observed in both types of simulator, but further analysis showed that not all drivers reduced their speed, and that indeed some drivers increased their speed during task completion. These increases and decreases in speed were similar across the two driving environments, suggesting that the effect of workload imposed by the IVIS tasks was similar in the two simulator environments.

However, drivers rated their driving performance as being worse when they drove the LabSim, and this may reflect two separate components of driving behaviour that were found to deteriorate with distraction – headway and lateral control. There were differences between the two driving environments when the headway distributions were studied. When using LabSim, drivers were more inclined to spend longer periods of time at shorter headways. This may be an indication of reduced realism or perceived risk presented in the LabSim which could have contributed to the decrease in subjective ratings that were observed in the LabSim.

With regards to lateral control, most tasks induced a decrease in lateral position variation, probably as a direct result of the speed reductions noted above. In contrast to the speed results, there were some differences in lateral control observed between the Driving Simulator and LabSim. Drivers exhibited poorer lateral control in the LabSim – and this was attributed directly to their performance on straight sections of road. Drivers using the LabSim were not able to control the “vehicle” as competently as in the Driving Simulator when driving on straight sections of road, during task completion. This poorer vehicle control could have affected the subjective ratings.

In summary, LabSim was able to reproduce similar results for speed choice, but not for lateral performance. Drivers have more difficulty in controlling the vehicle, perhaps as a direct result of the lack of field of view in the LabSim and reduced feedback from the vehicle controls.

Kappé et al. (1999) investigated the effect of horizontal field of view whereby drivers were required to perform a lane-keeping task whilst correcting for a slight side-wind. The results showed improved steering performance when the drivers experienced, at a constant resolution, a wide field of view as opposed to a narrow one.

These results do not imply that low-cost simulators can play no role in the evaluation of in-vehicle information systems; their limitations simply have to be taken into account and supplemented where necessary with a more sophisticated tool. The beauty of a low-cost tool is that it can be used early in the design process and, given the results derived in this study, one may be able to draw tentative conclusions about the likely effects of distraction on driving performance. This then allows scope for redesign before more elaborate and financially incumbent evaluations are carried out leading to the development of IVIS that mitigate driver distraction yet retain their utility.

Acknowlegements

The authors wish to thank the European Commission for the financial support of the HASTE project and to the reviewers who provided useful comments on an earlier draft of the manuscript.

References

Alicandri, E., Roberts, K., Walker, J., 1986. A validation study of the DoT/FHWA simulator (HYSIM). U.S. Department of Transportion, Federal Highway Administration. FHWA/RD-86/067.

Anderson, S.W., Rizzo, M., Skaar, N., Stierman, L., Cavaco, S., Dawson, J., Damasio, H., 2007. Amnesia and driving. Journal of Clinical and Experimental Neuropsychology 29 (1), 1-12.

Blakemore, M.R., Snowdon, R.J.,1999. The effect of contrast upon perceived speed: a general phenomenon? Perception, 28(1), 33-48.

Blakemore, M.R., Snowdon, R.J., 2000. Textured backgrounds alter perceived speed. Vision Research, 40(6), 629-638.

Blana, E., 1999. Behavioural validation of a fixed-base driving simulator. Proceedings of the Driving Simulation Conference, DSC99, Paris, France, pp. 227-241.

Boer, E.R., Girshik, A.R, Yamamura, T., 2001. Affording Realistic Stopping Behaviour: a Cardinal Challenge for Driving Simulation. Proceeding of the First Human Centred Transportation Simulation Conference, 4th-7th November 2001, Iowa City, Iowa.

Bremmer, F., Lappe, M.,1999. The use of optical velocities for distance discrimination and reproduction during visually simulated self motion. Experimental Brain Research, 127(1), 33-42.

Broughton, K.L.M., Switzer, F., Scott, D., 2007. Car following decisions under three visibility conditions and two speeds tested with a driving simulator. Accident Analysis and Prevention 39 (1), 106-116.

Carsten, O.M.J., Groeger, J.A., Blana, E., Jamson, A.H. 1997. Driver Performance in the EPSRC Driving Simulator: A Validation Study. Final report for EPSRC project GR/K56162.

Carsten, O.M.J, Brookhuis, K., 2005. The relationship between distraction and driving performance: towards a test regime for in-vehicle information systems. Transportation Research Part F, 8 (2), 75-77.

Carter, C.J., Laya, O., 1998. Drivers' visual search in a field study and in a driving simulator. Vision in Vehicles VI. Gale, A.G. et al. (Eds.): Elsevier, Amsterdam.

Charlton, S.G., 2006. Conspicuity, memorability, comprehension, and priming in road hazard warning signs. Accident Analysis and Prevention 38 (3), 496-506.

De Valck, E., Quanten, S., Cluydts, R., Berckmans, D., 2006. Day versus night driving in real traffic and on a driving simulator during an 800km all-highway drive. International Journal of Vehicle Design 42 (1/2), 119 - 133.

Duh, H. B. L., Parker, D. E., Furness, T. A., 2004. An independent visual background reduced simulator sickness in a driving simulator. Presence 13, 578–588.

Duncan, B., 1995. Calibration trials of the TRL driving simulator. TRL PA/3079/95. S221A/RB.

Gogel, W.C., Tietz, J.D., 1979. A comparison of oculomotor and motion parallax cues of egocentric distance. Vision Research, 19(10), 1161-1170.

Groeger, J.A., Carsten, O.M.J., Blana, E., Jamson, A.H., 1997. Speed and distance estimation under simulated conditions. In Gale, A.G., Brown, I.D., Haslegrave, C.M. and Taylor, S.P. (Eds.): Vision in Vehicles VII. Elsevier Science, Amsterdam.

Howard, I.P., Rogers, B.J., 1995. Binocular vision and stereopsis. Oxford University Press.

Howarth, P.A.,1998. Oculomotor changes within virtual environments. Applied Ergonomics, 30, 59-67.

Jamson, A.H., 2000. Driving simulator validity: issues of field of view and resolution. Proceedings of the Driving Simulation Conference, DSC2000, Paris, France, 57-64.

Jamson, A.H., Mouta, S., 2004. More bang for your buck? A cross-simulator evaluation study. Proceedings of the Driving Simulator Conference DSC 2004, 321-332.

Jamson, A.H., Whiffin, P.G., Burchill, P.M., 2007. Driver Response to Controllable Failures of Fixed and Variable Gain Steering. International Journal of Vehicle Design, 45(3), pp.361–378.

Kappé, B., Korteling, J.E., van Erp, J.B.F., 1999. Effects of Head-slaved and Peripherpal Images on Display Efficiency. Human Factors 41 (3), 453-466.

Kaptein, N. A., Theeuwes, J., Van der Horst, R., 1996. Driving simulator validity: some considerations. Transportation Research Record, 1550, 30-36.

LaViola, J. J. 2000. A discussion of cybersickness in virtual environments. SIGCHI Bulletin 32:47–56.

Lee, D. N. 1980. The optic flow field. Philosophical Transactions of the Royal Society of London, Series B, (290), 169-179.

McDonald W.A., Hoffman E.R. 1980. Review of relationships between steering wheel reversal rate and driving task demand. Human Factors (22), 733-739.

McKnight, A. J., McKnight, A. S., 1993. The effect of cellular phone use upon driver attention. Accident Analysis and Prevention, 25, 259–265.

Michon J.A., 1985. A critical view of driver behaviour models. What do we know, what should we do? In. L Evans & RC Schwing (Eds): Human behaviour and traffic safety, Plenum Press, New York.

Neale, J. M., & Liebert, R. M.,1986. Science and Behavior: An introduction to methods of research (3rd. Edn). New Jersey. Prentice Hall.

Pacejka, H. B., Besselink, I. J. M., 1997. Magic Formula Tyre Model with Transient Properties. Supplement to Vehicle System Dynamics (27), 234-249.

Peltola, H., 2002. Weather related ISA – experience from first studies. ICTCT Workshop on Intelligent Speed Adaptation, Nagoya, May 2002.

Philip, P., Sagaspe, P., Taillard, J., Valtat, C., Moore, N., Åkerstedt, T., Charles, A., Bioulac, B., 2005. Fatigue, sleepiness, and performance in simulated versus real driving conditions. Sleep 28 (12), 1511-1516.

Reed, M.P., Green, P.A., 1999. Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task. Ergonomics 42 (8), 1015 1037.

Riemersma, J.B.J, Van der Horst, A.R.A. and Hoekstra, W., 1990. The validity of a driving simulator in evaluating speed-reducing measures. Traffic Engineering and Control, pp 416-420.

Rizzo, M., R. A. Sheffield, L. Stierman, J. Dawson, 2003. Demographic and driving performance factors in simulator adaptation syndrome. Paper presented at the 2nd International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design, The Grand Summit Resort Hotel and Conference Center, Park City, Utah.

Rogers, B., Graham, M., 1979. Motion parallax and an independent cue for depth perception. Perception, 8(1), 125-134.

Sayers, M.W., Han, D.S., 1996. A Generic Multibody Vehicle Model for Simulating Handling and Braking. Supplement to Vehicle System Dynamics 25, 599-613.

Shechtman, O., Classen, S., Stephens, B., Bendixen, R., Belchior, P., Sandhu, M., McCarthy, D. Davis, E., 2007. The impact of intersection design on simulated driving performance of young and senior adults. Traffic Injury Prevention 8 (1), 78-86.

Steyvers, F.J.J.M., De Waard, D., 2000. Road-edge delineation in rural areas: effects on driving behaviour. Ergonomics 43(2), 223-238.

Strayer, D. L., Drews, F. A., Johnston, W. A., 2003. Cell phone induced failures of visual attention during simulated driving. Journal of Experimental Psychology: Applied, 9, 23–52.

Takeuchi, T., De, V., 2000. Velocity discrimination in scotopic vision. Vision Research, 40, 2011-2024.