Behavioural Research in an Advanced Driving Simulator – Experiences of the VTI System


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- EXPERIENCES OF THE VTI SYSTEM -

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ABSTRACT

The VTI driving simulator is described briefly, and aspects such as controllability, realism, validity, and motion sickness are discussed. The experience of using a simulator is accounted for. As an example, a study of mobile phone effects on driver behaviour is reported, focusing on methodological aspects. The paper ends with an extensive literature list containing behavioural studies performed in the simulator.

THE VTI SIMULATOR

The VTI driving simulator consists of six subsystems (Nordmark, 1990), all controlled to interact in a way that should evoke impressions, reactions and actions which are very much alike those experienced by a driver in a real driving situation. In the computer system with its simulation model, vehicle systems such as engine, brakes, transmission can be modelled, as can vehicle characteristics such as front wheel drive, rear wheel drive, and various levels of under- and oversteer. The moving base system has three degrees of freedom, and can simulate accelerations in different directions through roll and pitch rotations as well as through linear lateral motions of the car body. The visual system presents a continuously varying scenery on a 120° wide screen situated 2.5 metres in front of the driver. A variety of road conditions can be created, such as continuously varying road curvature, different kinds of details (lines, wheel tracks, macro texture), different road types (asphalt highway, narrow gravel road), and different friction levels. Various sight conditions, for example clear day, fog, and darkness, can be simulated. Components like road signs, post-mounted delineators, barriers and vehicles can be added and controlled. The sound system consists of six channels. Treble speakers and bass midrange speakers are used for noise generation. Besides, large loud-speakers allow the generation of high-level low-frequency sound (infra sound). Sound spectra can be created artificially, or by digitising spectra recorded during real driving. In the vibration system, vibrations resulting from the road-vehicle contact are created. Vibration spectra can either be generated by the use of a mathematical vibration model of the vehicle, or vertical acceleration data recorded in a real vehicle. The air temperature within the car body can be set and controlled by means of a temperature system.

WHY ARE WE USING A DRIVING SIMULATOR?

Controllability

Like laboratory methods in general, simulators offer high precision, reliability and controllability, factors which are all very important in behavioural research. One or a couple of variables can thus easily be varied systematically, while keeping all other variables constant, a possibility which makes the driving simulator highly convenient for comparative effect studies. Because the environmental as well as experimental conditions can be kept constant, exposing all drivers to identical circumstances, the required number of subjects is less than for field studies in order to attain the same statistical power in the results.

Dangerous situations and conditions

The demands from today's traffic system can be very high and difficult to cope with, a fact that sometimes finds its expression in "forcing" drivers into unwanted, more or less critical situations. Possible reasons are short time intervals for detecting, deciding and acting due to high speed levels and complex traffic situations, and also an increasing number of sources for divided attention. In the simulator, driver behaviour under demanding conditions can be investigated to the point of critical situations, and even to the point of colliding or driving off the road. Not least important is that driver actions (or lack of actions) preceding critical situations and accidents are possible to monitor. Such monitoring generates knowledge about driver behaviour and problems that constitutes a valuable basis for research dealing with questions such as: in which situations do
drivers need support?, what type of support do they need? and how should a support system be designed?

For studying driver performance under the influence of alcohol and drugs, a driving simulator seems to be the only method. Furthermore, drivers suffering from mental overload, heavy fatigue (Petit et al., 1990) and certain medical disorders, for example visual field defects (Lövsund et al., 1991) or the sleep apnea syndrome (Haraldsson et al., 1991) may be unethical and difficult to study in real traffic. At the same time, it is important to gain knowledge about driving strategies developed by these drivers, and about the type and severity of safety related behavioural effects that are likely to occur under these driver conditions.

Conceptual solutions

Today, huge resources and efforts are put into the development of driver support systems. In the simulator, effects of introducing such systems can be studied already in the conceptual phase (Nilsson et al., 1991; Nilsson and Alm, 1991b). Effects of system functionality and MMI (Man Machine Interaction) design on driver behaviour, acceptance and usability are of certain interest. Different system aspects can be varied systematically and studied one by one under exactly the same conditions. The relative effectiveness of the various solutions can be compared, concerning expected safety enhancement and driver support, prior to building prototypes and implementing them in real vehicles. Also road layouts including lining, infrastructure, tunnels etc. can be simulated before a road is built, in order to gain knowledge about potential driver reactions, and to avoid pitfalls.

Data collection

The recording of data is facilitated in the simulator because many potential dependent variables already exist as parameters in the simulation model. The simulator method also benefits from high and relatively easy accessibility to extensive driver monitoring and recording equipment, such as video cameras, eye and head motion trackers and various devices for physiological measurements.

LIMITATIONS REQUIRING CONSIDERATION

Realism

Real traffic is set up by an almost infinite number of situations, which vary in different respects. Also, "stochastic" events with various degrees of uncertainty appear. The described reality is of course impossible to fully reproduce in a simulator, no matter how advanced. Driver behaviour in, for example monotonous driving tasks and tasks which do not require too many components and details may very well be studied without a complete representation. For other research problems, where more complex traffic situations need to be studied, a much higher level of realism is required, in order not to misinterpret obtained results.

In several of the studies conducted in the VTI driving simulator the question "How realistic do you think the driving in the simulator was?" has been asked. Results from some studies are given in Table 1. All experimental conditions appearing in the respective study are taken together. It is by no means unexpected to find that the lowest realism and also some "not at all realistic" ratings appear in the studies of anti-collision and vision enhancement systems. These devices are not in common use yet, and may themselves add unrealism to the situation. Also, the fact that 5 % of the elderly subjects in the mobile telephone study estimated the driving to be "not at all realistic" may very well reflect that using a mobile telephone is an unrealistic task for these drivers.

Table 1 Estimated levels of realism in the VTI driving simulator. Means, standard deviations (SD) and proportions of "1" and "7" for the subjects' ratings on a seven-point rating scale from "not at all realistic" (=1) to "very realistic" (=7). Selected studies.

<table>
<thead>
<tr>
<th>Device tested</th>
<th>Mean</th>
<th>SD</th>
<th>&quot;1&quot;</th>
<th>&quot;7&quot;</th>
<th>n</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile telephone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>young</td>
<td>5.1</td>
<td>1.2</td>
<td>0%</td>
<td>10%</td>
<td>40</td>
<td>Alm and Nilsson, 1990</td>
</tr>
<tr>
<td>elderly</td>
<td>5.1</td>
<td>1.9</td>
<td>5%</td>
<td>25%</td>
<td>20</td>
<td>Nilsson and Alm, 1991a</td>
</tr>
<tr>
<td>Anti-collision</td>
<td>4.1</td>
<td>1.7</td>
<td>8%</td>
<td>5%</td>
<td>40</td>
<td>Nilsson et al., 1991</td>
</tr>
<tr>
<td>Vision enhancement</td>
<td>4.6</td>
<td>1.3</td>
<td>4%</td>
<td>0%</td>
<td>24</td>
<td>Nilsson and Alm, 1991b</td>
</tr>
<tr>
<td>Hand controls</td>
<td>5.1</td>
<td>1.1</td>
<td>0%</td>
<td>10%</td>
<td>52</td>
<td>Peters, 1993</td>
</tr>
</tbody>
</table>
Validity

The validity is not high by virtue just because a study is performed using a real car in real traffic, and low because a study is performed in a driving simulator. One very important step for a behavioural scientist is to decide which studies to perform in which environment, in order to benefit from methodological possibilities and to avoid drawbacks effects. Correctly applied, field studies and simulator studies should complement each other, forming a powerful and valuable couple. Despite the method used, the choice of measures is a crucial step for obtained results to reflect the aspects and conditions one intended to study. Although the validity question is continuously considered, it has to be studied further in experiments focusing on the specific aspect. Some indications are, however, available. Eye movements in a curve negotiation task (Laya, 1990) and responses to different levels of cognitive task demands (Harms, 1989) have shown both coincidence and differences between field and simulator studies. The speed controlling task has shown strong similarities in terms of the variability coefficient (SD/mean) (Nilsson and Alm, 1991b), and when studying driver alertness, two levels could be discriminated in the simulator with good correspondence on the road (Petit et al., 1991).

Physical laws

The ranges of roll, pitch and lateral motions allowed in the simulator limit the accelerations which can be generated during a driving manoeuvre. In a real vehicle there is a time delay from a driver initiated action by steering wheel or pedal until the vehicle "responds" by turning or decelerating. In modern passenger cars the delay is in the order of 100 ms. When the "simulator driver" turns the steering wheel, an additional, simulator related delay is introduced because a new vehicle state has to be calculated before the vehicle can respond, and a new scenery has to be drawn accordingly on the screen. The total additional delay in the VTI simulator is 40 ms, which is extremely short. For pure vehicle handling studies a short delay is crucial, while the requirements are more moderate for studying "normal" driving situations. Even a short delay may, however, have implications for motion sickness. The physical limitations might be experienced by the driver as a lack of correspondence between movements and visual impressions, i.e. as a slowly reacting vehicle.

Motion sickness

Motion sickness is usually explained by a mismatch between visual, vestibular, and proprioceptive impressions. The tendency for motion sickness varies between subjects, and it is difficult to predict who will be sick in a driving simulator. Latent as well as known tendencies can probably be awakened and strengthened, respectively, due to the above mentioned limitations to fully reproduce movements and accelerations. The introduced additional time delay is also a possible source of motion sickness. The visual impression from the screen itself causes impaired well-being in some drivers. From our experience it is obvious that the strongest implication for motion sickness in a simulator is a driving task containing many sharp bends and requiring many fast and large manoeuvres. "Normal" driving rarely introduces this type of problems.

Motion sickness has not been a pronounced problem in the VTI simulator. The probable reasons are, a selective choice of applications, "pilotizing" to carefully design and evaluate test routes taking into account driver opinions and sensations, and the extremely short methodological time delay. In a recent study (Peters, 1993), some narrow bends were introduced because the focus was on the control level of the driving task. A comparably large proportion of the subjects (7 of 72) also had to interrupt the experiment because of motion sickness. Besides, two subjects completed the test despite feeling sick.

HOW WE USE OUR DRIVING SIMULATOR

Using the VTI driving simulator have taught us some valuable lessons, namely:
* Critical selection of applications, and courage to renounce unsuitable ones are the basis for useful results.
* Critical selection and evaluation of measures help finding those really reflecting aspects with implications for traffic safety, driver acceptance, usability etc.
* Confounding effects on the results because of unfamiliarity with simulator driving, vehicle characteristics and the specific experimental tasks can be avoided by letting subjects practise in the simulator
* Unrealistic driver behaviour, because subjects are not exposed to any real danger, can be prevented by care-
fully instructing and pretraining them to drive as they usually would do under comparable conditions in real life. Interpretation of results can be facilitated by not covering "all" aspects in an extensive study, but performing many "small" studies, focusing on one specific aspect each, and instead benefit from being able to keep the conditions constant between studies.

**EXAMPLE**

A study of the effects on driving performance from talking over a mobile phone in a car following situation is reported (Alm and Nilsson, 1991).

**Method**

**Subjects.** Forty subjects participated in the study, twenty below and twenty above or equal to 60 years of age. All the subjects were experienced drivers, meaning that they had had their driving licence for at least five years and drove at least 10,000 km per year.

**Driving task.** The road used was a relatively straight two-lane road with high friction, 80 km long and 7 m wide. The sight condition was slightly hazy with a sight distance of approximately 400 m. Each subject caught up with and followed another car 16 times during the experimental session. Four of the cars ahead braked, four activated the right direction indicator, and eight just drove. When a car ahead braked (brake lights lit), the subjects should brake as fast as possible, and when a car ahead activated its right direction indicator they should activate their left direction indicator. The simulator made possible that all cars ahead appeared in the same positions along the road, and behaved in the same way for all subjects. In following, the distance between the subjects' car and the car ahead was controlled to be constant until the latter braked or activated the direction indicator. All the subjects had thus to detect these actions from the same viewing distance. Oncoming traffic appeared in the opposite lane.

**Telephone task.** A handsfree mobile telephone was used. It rang eight times during the experimental session, at the same positions along the road for all subjects, when they were following another car. Four times the followed car ahead braked, and four times it "blinked". The Working Memory Span Test was used because it could be repeated without strong learning effects, its presentation time could be kept constant, and it allowed an easy evaluation of how well the subjects performed the task. The test contained a working memory part and a decision part.

**Measures.** Driving performance was measured by choice reaction time (braking), headway, speed, and lateral position. The collection of data was controlled by the simulator's main computer. The data were recorded from exactly the same road sections for all subjects. A simplified version (RTLX) of the NASA-TLX rating scale was used to measure the subjects' workload. The verbal answers to the telephone task were recorded on tape.

**Procedure.** Young and elderly subjects were randomly assigned to the telephone or control condition. Both written and verbal instructions were given about how to drive the simulator and about the experimental tasks. Subjects in the telephone groups had some training on the telephone task. All subjects practised the respective experimental tasks in the simulator, assisted by the experiment leader. After a brake, they drove the actual test route and completed the experiment by answering the NASA-RTLX rating scale.

**Design.** The study was conducted as a two by two factorial design; one factor concerning use of mobile telephone (phone versus control) and the other factor concerning age (young versus old).

**Results**

**Reaction time.** The mean choice reaction times (braking) for the young subjects were 2.19 s when talking on the phone and 1.63 s when only driving. For the elderly subjects the corresponding mean values were 3.48 s and 2.02 s, respectively. A two-way ANOVA confirmed significant effects of both telephone use ($p<.05$) and age ($p<.05$).

**Headway.** Headway was considered from the moment the subjects could control their speed freely, i.e. after the car ahead had braked. For the young subjects, the means of minimum headway were 38 m when talking on the phone and 46 m when only driving. The corresponding values for the elderly subjects were 47 m and 53 m, respectively. Again, the ANOVA showed significant effects of telephone use ($p<.05$) and age ($p<.05$).

**Speed.** The allowed speed level was constrained by the experimental design, which made it impossible to overtake. Therefore, the speeds of the cars driving ahead also imposed restrictions on speed choice. Anyhow, the elderly subjects drove somewhat slower than the
young subjects when using the phone. The young subjects were also approaching significantly faster (p < .05) than the elderly subjects. The difference was 11.8 km/h.

Lateral position. The lateral position and its variation did not show any significant effects during the phone calls. The steering ability was thus not influenced by telephone use, and did not differ between age groups.

Workload. Subjects talking on the phone and driving rated the workload aspects mental demand, time pressure, effort and frustration higher than did subjects that only drove (significant effects, p < .05). On the other hand, subjects that did not use the telephone rated their performance higher (p < .05). The only effect of age was that the young subjects rated their effort significantly higher (p < .05) than the elderly subjects.

Telephone task. No statistically significant difference between young and elderly subjects was found. Thus, both groups paid similar attention to the task.

Conclusions

* Drivers' ability to react quickly in a car following situation was impaired when they were talking on the mobile phone. The prolongations of reaction time, 0.6 s for young drivers and 1.5 s for elderly drivers, imply stopping distances which are increased by, respectively, 8 and 21 m when driving in 50 km/h.

* Neither young nor elderly drivers compensated for the longer reaction time by increasing the headway. The distance to a car ahead was even shorter than for drivers that only drove.

* Drivers estimated their workload to be higher when driving and conversing over the phone. Thus, they did not pace the task to keep the workload level constant.

* It is likely to assume that the risk for an accident may increase when using a mobile telephone during car following.

REFERENCES


