DSC North America 2003 Proceedings, Dearborn, Michigan, October 8-10, 2003 (ISSN 1546-5071).

TRANSFER OF TRAINING IN AN ADVANCED DRIVING SIMULATOR: COMPARISON BETWEEN REAL WORLD ENVIRONMENT AND SIMULATION IN A MANOEUVRING DRIVING TASK

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Submitted 8/29/2003

ABSTRACT

Driving instructors and novice drivers often remain sceptical about the realistic learning potential driving simulators offer to real world driving tasks. The aim of this experiment was to compare the effectiveness of training in the real system with an advanced driving simulator. The participants were required to learn a specific driving manoeuvre: reverse park a truck with an attached trailer from one side of the street to the other. 50 experienced truck drivers were recruited to participate in the experiment. Initially all participants performed the manoeuvre 3 times in the real system (i.e. in the truck). If a participant completed the task successfully they were credited with a score of '1', if a participant was unable to complete the task successfully he was credited with a score of '0'. The time taken to complete the task was also recorded. The participants were then divided into two groups. The two groups proceeded to train the task in one of the two training environments: Group A practised 5 times in the advanced driving simulator, whilst group B practised 5 times in the real system. Once training had been completed, all participants were asked to perform the manoeuvre an additional 3 times in the real system. Successful completion of the task was scored and the time taken to complete the task was once again recorded. The difference in scores between the initial 3 performances and the final 3 performances in the real system were measured allowing a direct comparison between the effectiveness of training in the two learning environments to be made. Whilst the t-test analysis of results indicated no significant difference in the success of completing the task between training groups, an insignificant difference in the time taken to perform the task between the training groups was found. It is suggested by the authors that the reason for this difference was due to the highly sensitive nature of the simulator that taught participants to be more cautious than necessary when performing the manoeuvre. Overall the results indicated a positive transfer of training from the driving simulator into the real system in this specific driving task.

INTRODUCTION

The benefits of using driving simulators as investigative tools in scientific research is widely acknowledged, which has resulted in extensive use of such systems within the scientific research community (e.g. Horne, 1991 (1); Hein, 1993 (2); Guyard, 1993 (3); Nilsson, 1993 (4); Allen, 1994 (5); Levine, 1996 (6); Triggs, 1999 (7); Godley, 2002 (8)). Driving simulators are also well known as interactive tools used to investigate different driving and manufacturing related items by car manufacturing companies (e.g. Käding, 1994 (9), Huesmann et. al., 2003 (10)). In general, driving simulators are used in three main fields of expertise (von Bressensdorf et al., 1995 (11)):

- investigating human factors and behaviour
- investigating and evaluating new appliances for vehicles
- use as an educational instrument for learning and continuing education

However, whilst driving simulators as research tools remain popular, driving simulators as interactive education instruments remain relatively underused despite possessing several advantages over training in the actual system, such as issues concerning safety, ecology and enhanced training:

Safety: Simulators offer the opportunity to practice a task within a safe learning environment without the inherent risks and consequences that training in the real system places on trainees and equipment. This allows critical or dangerous driving scenarios to be simulated and therefore allows training to be performed in a safe and effective environment.

Ecological: The environmental costs of most driving simulators are limited to the electricity required to power them. In contrast the amount of pollution (e.g. car exhaust fumes) generated by accumulated training in the real system is considerable. When learning to drive, the trainee is often required to perform tasks in very specific scenarios and locations. A trainee in the real system must spend time to travel to these specific locations whilst a simulator allows the location to be reached within a few clicks of a mouse button.

Enhanced training: Simulators offer unlimited repeatability that allows a task to be trained as often and frequently as a user requires. They are also able to adapt the training curriculum to the learning pace and needs of the individual trainee. The instructor is able to pause a scenario to give the trainee immediate feedback. Dieterich and Tomaske (12) describe the following didactic advantages for driving simulators:

- *weight-belt effect:* the task presented to the user is more difficult in the simulator than in the real system
- *aggregation effect:* specific learning items occur much more often
- *multi-coding effect:* revisiting the scene using replay possibilities
- *isolation effect:* unhinge a specific training item out of a complex training task
- *emancipation effect:* autonomous and independent learning by the trainee is possible

The sum of these advantages suggests that driving simulators are powerful training environments. But despite these advantages, simulators remain underused as training devices. The question arises: why? The answer is two-fold; firstly, the quality of simulator based training is often regarded with scepticism; and secondly, the cost of building most modern driving simulators remains relatively high:

Cost of driving simulators: One of the main reasons why driving simulators remain under used in the field of education is the high cost associated with well-equipped driving simulators. In comparison to the real system, high performance driving simulators (e.g. full motion, large visual display, precise computer models of the system, a large range of training possibilities) are expensive. A comparison of acquisition costs between a truck with an attached trailer and a high-end driving simulator reveals that the simulator costs ten times as much as the real system. Of course, there are low-cost driving simulators that have proven to be effective training devices. However, it seems a logical conclusion that a simulator that highly resembles the actual system, is more effective at transferring skill to the actual system than a device that less resembles the actual system. However, due to the extreme difficulty and expense incurred, complete duplication of the actual system is often undesirable. It is therefore important that simulator designers establish what deviations from the actual system can be made without compromising the effectiveness of training. If simulators are to be considered a viable alternative to training in the actual system, it is essential to determine what elements of the actual system are required without increasing simulator costs to an unsatisfactory degree.

Acceptance by the users: Another important reason why driving simulators remain underused in the educational field is the lack of acceptance by users to train with such systems. These days, computers are integrated into the general lives of young people and therefore such users have no qualms with using driving simulators. For many young driving trainees the opportunity to train in an independent training environment at a self paced rhythm, without a trainer looking over his or her shoulder is a positive advantage. However, older trainees who do not possess much in the way of computer experience maybe hesitant and sceptical of driving simulators. The sentiment expressed is often: “Simulators are interesting and fun but they are not the same as the real system. I think that I would learn faster in a real car.”

Acceptance by training supervisors: Often training supervisors are also sceptical about the use of driving simulators in the curriculum of education because they are afraid that these devices will supplant them and will consequently cost them their jobs.

Transfer of training: Presently, the scientific knowledge of if, and how, skills learned in a virtual environment are transferred into the real system is limited. There are a few studies concerning the physiological, behavioural and technical differences between simulated environments and reality (e.g. Boer et al., 2000 (13)), but the field of training transfer remains a source of ambiguity. In an early experiment, Kozak et al. (14) stated that the ability of simulators to transfer training into real system was ineffective. However, the trainees being tested *did* learn something but were unable to transfer it into the real system. He acknowledged that these findings may be due to barriers imposed by the technological limitations of the time. In contrast with Kozaks findings, a more recent investigation (Rose et al., 2000 (15)) revealed similar levels of post-training performance in the real system when training a task in a simulator and in the real system. With caution, the authors suggested that the transfer of training experienced in the experiment may not occur when training an alternative task. The aforementioned authors Dieterich and Tomaske (12) found that trainees in a driving simulator performed better then their counterparts on the real system. However, drivers learning in the real system (i.e. a truck) were allowed ‘free reign’ and were not constrained to performing a specific task or tasks (they had to “take” what traffic is “giving” them), whilst those training in the simulator were following a structured and controlled learning plan. This large variability in training content between the training groups makes it difficult to make a direct comparison between the learning environments, and limits the conclusions that can be made from the experiment.

The aim of this paper is to identify whether simulators are effective devices at transferring skill to the real system. The experiment made use of two groups of trainees: Group A received training of a task in an advanced driving simulator; Group B received an equivalent amount of training in the real system, then both groups proceeded to be tested on the learned task in the real system. Their performances were recorded and compared with one another. In comparison with a recent experiment performed by Dieterich and Tomaske (12), both groups learned the same task whilst training, which allowed a direct comparison to be made between the two learning groups.

The hypothesis was that trainees training in the driving simulator would not perform as well as their counterparts from the real system despite the well-equipped and modern advantages of the simulator used.

METHOD

The experiment presented in this paper is a comparison of training effectiveness between two different learning environments. The experimental procedure consisted of three phases (see fig.1): prior to experimentation participants were informed of the training task they were to learn. In the first phase all participants performed the task three times on the real system The second phase was the training stage: group A trained the task five times in the driving simulator whilst group B trained the same task five times on the real system. During phase three, all participants performed the task three times on the real system. A comparison between the performance results of the “basic” stage and the “testing” stage allowed the effectiveness of training to be measured. By comparing these training effectiveness measurements between the two groups, it was possible to make assertions about the effectiveness of training of the two learning environments.

DSC North America 2003 Proceedings, Dearborn, Michigan, October 8-10, 2003 (ISSN 1546-5071).

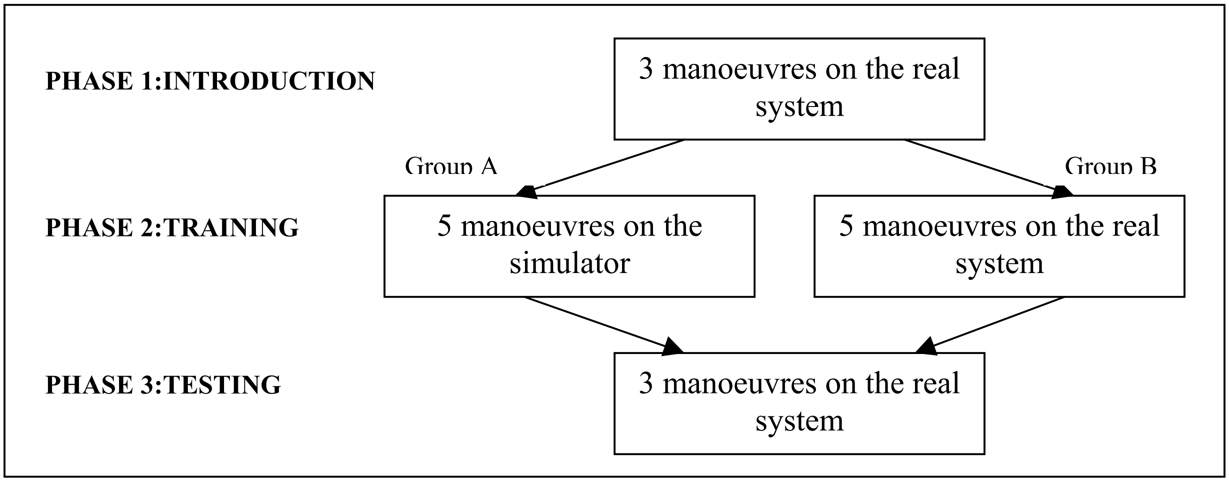

FIGURE 1 The test design of the experiment

Participants

In this experiment 50 experienced truck drivers aged between 21 and 67 years old (mean: 40.2; median: 39.5; 48 male and 2 female) participated in the experiment. Driving experience of participants ranged from infrequent truck driving (about 0-500 km per year) to professional truck drivers (about 100'000 km per year). The participants were separated into two balanced experimental groups. All participants possessed a truck driving licence. However, not all participants possessed a licence for driving a truck with a trailer. Participants were not paid.

Apparatus

The vehicle used in the experiment was a truck manufactured by Steyr (see Fig.2). This type of truck is used by the Swiss Army driving school and meets the legal requirements to allow those holding the Swiss truck driving license to operate it. Both the truck and the attached trailer were loaded with a 6000 kg weight.

FIGURE 2 The used truck-type from Steyr with an attached trailer

The simulation environment was a truck driving simulator called FATRAN built by Oerlikon Contraves (see Fig.3). This advanced driving simulator system is an exact replica of the Steyr truck cockpit and reproduces the behaviour of the real truck. The only motion present in the simulator is a longitudinal axis pitch at the drivers seat. The visual display is an about 160° to 40° collimation system with three projectors for the front view. Two standard monitors represent the view of the side rear mirrors.

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FIGURE 3 Exterior and interior view of FATRAN from Oerlikon Contraves Switzerland

Procedure

The participants were required to learn a specific driving manoeuvre: reverse park a truck with an attached trailer from one side of the street to the other (see Fig.4).

Initially all participants performed the manoeuvre 3 times in the truck (called "basic"). If a participant completed the task successfully they were credited with a score of '1', if a participant was unable to complete the task successfully he was credited with a score of '0'. The time taken to complete the task was recorded, as were the number of corrections incurred whilst manoeuvring the vehicle (Participants were permitted to correct driving mistakes whilst performing the manoeuvre, to ensure that the task was successfully completed). The participants were then divided into two groups. The two groups proceeded to train the task in one of the two training environments: Group A practised 5 times in the advanced driving simulator, whilst group B practised 5 times in the real system. Once training had been completed, all participants were asked to perform the manoeuvre an additional 3 times in the real system. Successful completion of the task was scored and time taken to complete the task was once again recorded.

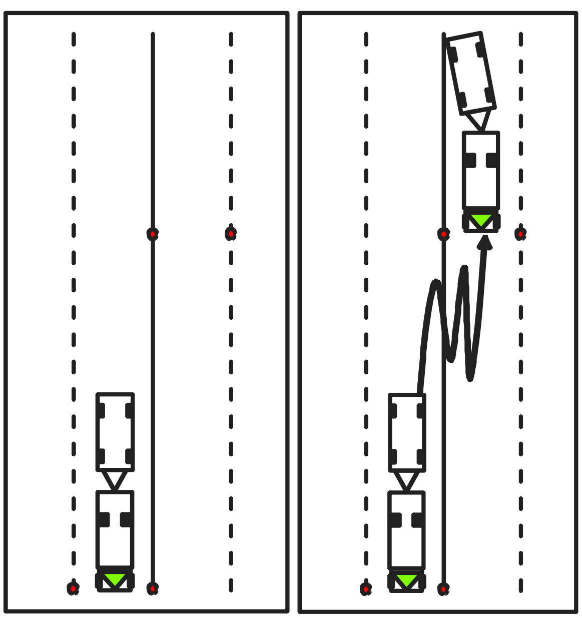

FIGURE 4 Schematic illustration of the reverse parking (left: start position; right: reverse parking with corrections)

RESULTS

In this section the results of the measured parameters "success" and "time taken" are presented. In addition, the results of the driving corrections (changing from backwards driving to forward driving and back again) are presented because these results are interesting when discussing the "time taken" results.

Success

Table 1 shows the scores of success and the counted t-test values. These scores are divided into: basic (phase 1) results; testing (phase 3) results; group A results and group B results. In addition, the calculated learning success scores are displayed.

TABLE 1 score of success and t-test amounts

	"basic"	"testing"	t-test group (dependent)	learning success
group A	**66**	**73**	**0.004****	**+ 7**
group B	**65**	**75**	**0.001****	**+ 10**
t-test experimental phase (independent)	**0.404**	**0.078[t]**		**0.287**

t = p < .1 * = p < .05 ** = p < 0.01

The maximum possible points obtained in each trial was 75 points.

Figure 5 shows the learning curve of the two experimental groups. The first three points show the average values of the two groups in the phase1. The last three points present the means of the two groups in the phase 3. Higher scores indicate better performance.

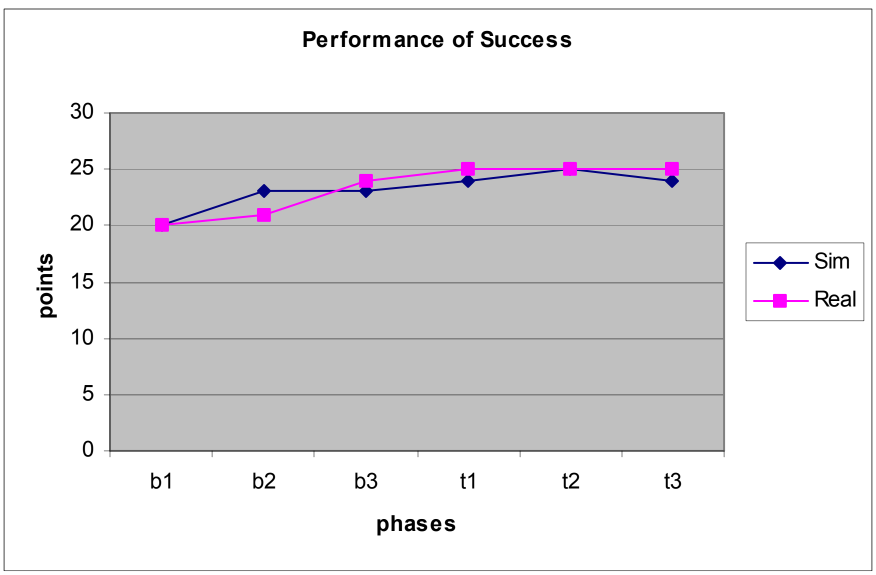

FIGURE 5 Learning curve of the factor "success"

Time to complete

Table 2 presents the time taken to perform the task and the counted t-test. These scores are divided into: basic (phase 1) results; testing (phase 3) results; group A results and group B results. In addition, the calculated learning success scores are displayed.

TABLE 2 used time and t-test amounts

	“basic” [sec.]	“testing” [sec.]	t-test group (dependent)	learning success [sec.]
group A	**23735**	**16577**	**4.632E-10****	**- 7158**
group B	**23626**	**14095**	**4.223E-13****	**- 9531**
t-test experimental phase (independent)	**0.479**	**0.067t**		**0.132**

t = p < .1 * = p < .05 ** = p < 0.01

The maximum time taken to perform the task was 45'000 [sec.].

Figure 6 shows the learning curve of the two experimental groups in the factor “used time”. The first three points show the average values of the two groups in the phase 1. The last three points present the means of the two groups in the phase 2. The less time taken to perform the task the better the trainees performed.

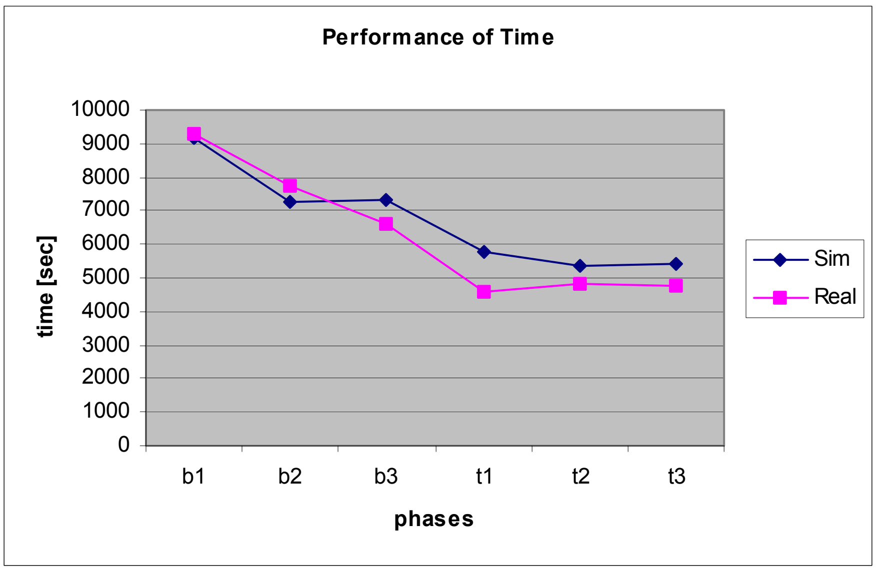

FIGURE 6 Learning curve of the factor “used time”

Corrections

Table 3 shows the scores of corrections and the counted t-test values. These scores are divided into: basic (phase 1) results; testing (phase 3) results; group A results; and, group B results. In addition, the computed learning success scores are displayed.

TABLE 3 score of corrections and t-test amounts

	“basic”	“testing”	t-test group (dependent)	learning success
group A	**184**	**119**	**0.000****	**- 65**
group B	**200**	**78**	**3.542E-7****	**- 122**
t-test experimental phase (independent)	**0.334**	**0.046***		**0.057t**

t = p < .1 * = p < .05 ** = p < 0.01

During the trials participants made corrections to their maneuvering of the vehicle in order to perform the task correctly. The participants were allowed to make as many corrections as they needed to make during the experiment. Participants were not penalized for making more or less corrections when maneuvering. However, the number of corrections made impacts heavily on the time taken to perform the task. The time taken to perform the task was a crucial factor in evaluating the successfulness of the task.

Figure 7 shows again the learning curve of the two experimental groups but in the factor “corrections”. Also here like at the factor “used time” less points means better performance.

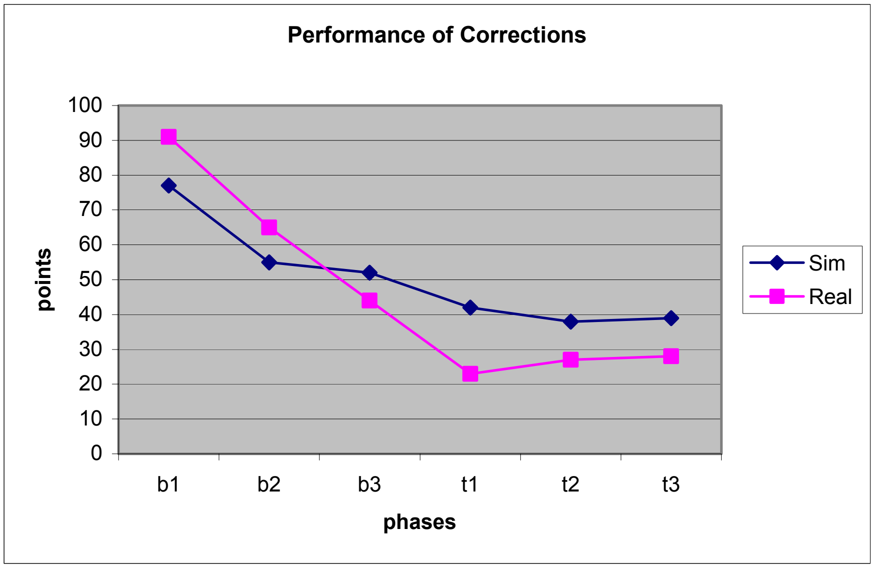

FIGURE 7 Learning curve of the factor “correction”

DISCUSSION

Success

The dependent group t-test indicates that both experimental groups significantly improved their skills at reverse parking a truck with an attached trailer during the training. The independent t-test of the whole “success” data found no significant difference between the groups. During the first phase of the experiment the results between the two groups are very similar. In contrast, during the third phase the results indicate that success is different between the two groups. However, this must be regarded with a certain amount of caution because if values are reaching a limit of points and in comparison between two groups of values one value reaches this limit and the other group is close to this limit statistical tests like the t-test evaluate this little difference between the two groups of values very high and therefore can show a tendency to significance. This happens here because the limit of points of 75 was reached by group B and group A was very close to this limit with 73 points. But this little difference was assessed by the statistical test very high.

The “success” learning curves show that learning between the groups is very similar. Although, Group A performed better during the second trial of phase 1 this statistic is not significant.

Time to complete

The highly significant values of the dependent t-test indicate that both training groups improved their skills with regard to the time taken to complete the task. However, the values of the independent t-test show a tendency for group B to perform faster during phase 3 than group A. This tendency is supported by the lower rank of t-test value of learning success comparison.

During the first trial of phase 3, the difference of learning curves of the two learning groups is largest. However, during all three trials of phase 3, group B performed better than group A. Both curves also show a similar decrease between the groups between phase 1 and phase 3.

Corrections

The highly significant results of the dependent t-test indicate that both training groups learnt to make less corrections in phase 3 of the experiment. However, there was a significant difference between the scores in phase 3 between the two learning groups. Group A made significantly more corrections than group B. In addition, the "corrections" learning curve of group B shows a more continuous process compared to group A.

CONCLUSION

Comparison between Reality and Simulation

Both learning groups possess similar results in the successful completion of the task during phase 3 (testing) of the experiment. However, although the successful completion of the task between the two learning groups was similar, two other measures indicated some discrepancy in results between the two learning groups: the time taken to complete the task and the number of driving corrections made during the task.

Group A took more time to complete the task and performed more driving corrections when performing the task than group B. Comments made by participants in group A were examined to explore this discrepancy further. The comments suggest that the task was harder to perform in the simulator than it was in the real system. The reason for this is that slight errors of steering that would be excused in the real system were treated with zero tolerance by the simulator. The fact that only 10% of trainees on group A managed to complete the task during phase 2 (training), tends to compliment the suggestion that the simulator consists of a far stricter method of training than the real system.

The results from the number of corrections the trainees made support the finding that there is a difference between the driving simulator and the real system. Although the number of driving corrections made by both learning groups was less in phase 3 (testing) than it was in phase 1 (introduction), group A made considerably more corrections than group B. A correlation analysis between the number of corrections and the time taken to complete the task shows a significant correlation between these two factors ($R= 0.779$).

The driving simulator forced the trainees to make more corrections whilst performing the simulated task because of the strict nature of the simulation model. The trainees learned to make many corrections in the simulator, and therefore behaved the same way in the real system, when performing phase 3.

Transfer of Training

As shown in the preceding chapter, negative transfer of training occurred during the experiment (i.e. the trainees in group A learnt to make many corrections, and transferred this behaviour to the real system). The negative feedback was a result of the extremely high sensitivity of steering designed into the simulator program. The instructors that developed the simulator task commented that the high requirements for precision imposed by the simulator on users was intentional. They suggested that trainees who can perform highly precise manoeuvring as required in the simulator task would require less effort on the less strict real system. However, what the designers failed to recognise is that those training on the simulator system, falsely believe that the task will be harder to perform than it really is on the real system. The trainee therefore transfers this perception to the real system. Because of the precise and strict nature of the simulator trainees learn to make many corrections on the simulated task and accepts that he or she will make many corrections when performing the task in the real system. The trainees do not perform better than those who have learned in the real system, in fact they take more time performing the task, because it takes them more time to make the considerable driving corrections that they have falsely learnt are part of the task.

The large gaps after the training sequence between the two learning curves at the factors „used time“ and „corrections“ underline the effect of the strict simulator training. At this phase the experimental group which trained on the driving simulator showed a less high performance than their counterparts probably because they transferred their training experiences (the system is reacting very strictly) from the driving simulator into the reality.

Driving Simulators as Training Tools

At the beginning of this paper, two suggestions were proposed as to why simulators remain underused as training devices. The first suggestion concerned the scepticism of trainees and trainers over the ability of simulators to transfer training to real system. The results of this experiment clearly indicate that transfer of training (both positive and negative) does occur from driving simulator to real system, as both training groups performed the task with equal success in the third phase of the experiment. It is the hope of the authors of this paper that this knowledge is used to convince trainers and trainees who are currently sceptical about the ability of simulators to rethink their beliefs and hopefully accept and implement such devices into their training curriculum in the future.

The second suggestion as to why simulators remain underused as training devices concerned the high costs of building driving simulators. Currently, very little is known as to what elements of a simulator are essential for transfer of training to the real system. The simulator used in this experiment possessed only limited motion, and yet, training to reverse park a truck with an attached trailer was successful in the simulator. Training of the task, therefore, did not require full motion simulation, which reduced the cost significantly of building the simulator. It is suggested by the authors that, a task analysis and user analysis be performed before any simulator is built, to determine the specific requirements of the task be designed for in the design of the simulator. This analysis will directly impact on the costs of building a task-specific simulator. In the Institute of Hygiene and Applied Physiology at the Swiss Federal Institute of Technology Zurich further investigations are planed to determine the different elements of simulator systems (e.g. motion, size of visual, vibration, mock up) and their influence and effect on transfer of training and the effectiveness of learning.

ACKNOWLEDGMENT

The authors would like to thank the FVS (Fonds für Verkehrssicherheit/Funds for Traffic Safety) for funding this research project which was conducted in partnership with BALOG (Bundesamt für Logistiktruppen/Federal Office of Logistic Troops).

REFERENCES

1. Horne, J. A. and Baumber, C. J. (1991), Time-of-day effects of alcohol intake on simulated driving performance in women. *Ergonomics*, Vol. 34, No. 11, 1377 – 1383

2. Hein, C. M. (1993), Driving Simulators: Six Years of Hands-On Experience at Hughes Aircraft Company. *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*, Santa Monica, CA: HFES, 607-611

3. Guyard, I. (1993), The Driving Simulator: an Aid for Ergonomic Design of Car Interiors. In: Gale A.G. et al. (Ed.) *Vision in Vehicles – IV*, Elsevier Science Publishers B. V., 311 – 320

4. Nilsson, L. (1993), Behavioural research in an advanced driving simulator – Experiences of the VTI system. *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*, Santa Monica, CA: HFES, 613-616

5. Allen, R. W., Parseghian, Z. and Rosenthal, T. J. (1994), Simulator Evaluation of Road Signs and Signals. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*, Santa Monica, CA: HFES, 903-906

6. Levine, O. H. and Mourant, R. R. (1996), Effect of visual Display Parameters on Driving Performance in a Virtual Environment Driving Simulator. *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting*, Santa Monica, CA: HFES, 1136-1140

7. Triggs, T. J. and Regan, M. A. (1999), Driving Simulation and Human Factors Research: A Report on an Australian Program. *Proceeding of the Driving Simulation Conference 1999*, Paris

8. Godley, S. T., Triggs, T. J. and Fildes, B. N. (2002), Driving simulator validation for speed research. *Accident Analysis and Prevention* 34 (2002), 589 – 600

9. Käding, W. (1994). The Daimler-Benz Driving Simulator, Technical Setup and Spectrum of Application. *Proceedings for the Dedicated Conferences on Mechatronics & Supercomputing Applications in the Transportation Industries*: Aachen, Germany, 31st Oct

10. Huesmann, A., Wisselmann, D. and Freymann, R. (2003) Der neue dynamische Fahrsimulator der BMW Fahrzeugforschung, *Simulation und Simulatoren – Mobilität virtuell gestalten – Simulation and Simulators – Virtual Mobility - ,VDI-Bericht 1745*, 59-67

11. von Bassensdorf, G., Heilig, B., Heinrich, H.Ch., Kamm, H., Käppler, W.D. und Weinand, M.(1995). Eignung von Pkw-Fahrsimulatoren für Fahrausbildung und Fahrerlaubnisprüfung. *Berichte der Bundesanstalt für Strassenwesen, Mensch und Sicherheit, Heft M 50*

12. Dieterich and Tomaske (2003) Technische und lernpsychologische Zusammenhänge bei Trainingssimulatoren für die Fahrausbildung, *Simulation und Simulatoren – Mobilität virtuell gestalten – Simulation and Simulators – Virtual Mobility - ,VDI-Bericht 1745*, 435-452

13. Boer, E.R., Yamamura, T., Kuge, N. and Girshick, A. (2000). Experiencing the same Road twice: A Driver Comparison between Simulation and Reality. *Proceeding of the Driving Simulation Conference 2000*, 33-55

14. Kozak, J.J., Hancock, P.A., Arthur, E.J. and Chrysler, S.T.(1993). Transfer of training from virtual reality. *Ergonomics*, Vol. 36, No.7, 777-784

15. Rose, F. D., Attree, E.A., Brooks, B.M., Perslow, D.M., Penn, P.R. and Ambihaipahan, N.(2000). Training in virtual environment: transfer to real world tasks and equivalence to real task training. *Ergonomics*, Vol. 43, No.4, 494-511