The Impact of Psychological and Demographic Parameters on Simulator Sickness

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Abstract: In a world, which is characterized by technical progress, virtual environment technologies become increasingly relevant. In this context, simulators are used as a cost and time efficient methods for investigating innovative developments, training effects, but also the influence of individual attributes such as the process of aging. Although the simulator technologies have been greatly developed in recent years, they are not able to perfectly replicate the real world, which causes problems of system adaptation and simulator sickness. In the paper at hand, we will focus both, the time of adaptation to the virtual environment and the phenomenon of simulator sickness under the aspect of mental abilities and the process of aging, based on a driving simulator study with 414 participants.

1 INTRODUCTION

Within a previous study, Sahami, Jenkins, and Sayed (Sahami et al., 2009) described the adaptation to a driving simulator as the process by which drivers adjust their existing driving skills to the simulator so that they can effectively control the simulated vehicle and drive it through the simulated environment. A key question in this context belongs to the time it takes until humans adapt to virtual environments in order to observe ”realistic” behavior. Previous studies mostly used a pre-defined period of time to practice from 5 to 15 min (Horberry et al., 2006) or in some case 30 min to several hours (van Winsum et al., 1999). An exception is the study conducted by O’Neill, Krueger, Van Hemel, McGowan, and Rogers (O’Neill et al., 1999), in which the participants were asked to practice two full days before starting the experiment. In contrast, Bass, Charlton and Bastin (Baas et al., 2000) used a very short practice time of around 2 min in examine truck drivers fatigue and fitness of duty. Along with a pre-defined period of time, pre-defined distances (Lewis-Evans and Charlton, 2006), or the subjective feeling of comfort of the participants (Takayama and Nass, 2008) are also frequently used. Nevertheless, such approaches do not ensure that adaptation has indeed occurred. One approach to determine the time of adaptation comes from McGehee, Lee, Rizzo, Dawson, and Bateman (McGehee et al., 2004). Their results show that drivers adapt within approximately 240s after starting the simulator scenario. Furthermore, McGehee et al. (McGehee et al., 2004) reported an age-related increase in the steering variability of older drivers, but no effect on adaptation rates. In the context of steering adaptation pattern, Sahami and Sayed (Sahami and Sayed, 2010) discussed the processes of motor-cognitive skills, cognitive-mental abilities, and the aspect of physiological transfer as responsible for the time humans need to adapt to virtual environments. Closely related to each other and discussed as result of a lack of adaptation, simulator sickness is described as a phenomenon including symptoms such as headache, sweating, dry mouth, drowsiness, disorientation, vertigo, nausea, dizziness, and vomiting (Brooks et al., 2010b), which are similar to those of motion sickness but typically less in their appearance (Kennedy et al., 1993). Previous studies reported experiences with simulator sickness in 80% to 95% of participants and a drop-out rate of 5% to 30% (Stanney et al., 2002). In this context, Balk, Bertola and Inman (Balk et al., 2013) discussed nausea and nausea-related symptoms as most likely described symptoms to fail to complete simulations. Regarding sex-related differences in the occurrence of simulator sickness, Garcia, Baldwin and Dworsky (Garcia et al., 2010) reported a lower level of simulator sickness in males compared to females as a function of fixed-base versus rotating base platform,

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which is in accordance with previous studies (Freund and Green, 2006). In the context of age-related differences there is a common agreement that older adults tend to be more susceptible to simulator sickness than younger participants (Brooks et al., 2010b). These findings are explained by Domeyer, Cassavaugh, and Backs (Domeyer et al., 2013) based on the fact of a lack of experience with simulated environments in the elderly. Mullen, Weaver, Riendeau, Morrison, and Bédard (Mullen et al., 2010) compared older adults who failed to complete a simulated drive because of simulator sickness and those who completed the simulation by using onroad driving performance, the Useful Field of View test, the Attention Network Test, and the Trail Making Test (A). Based on their results the authors suggested that cognitive differences are not associated with dropping out because of simulator sickness. In contrast, Kawano et al. (Kawano et al., 2012) reported a relation between visuospatial function and the onset of simulator sickness. For example, Rizzo et al. (Rizzo et al., 2003) reported a 2.4 times higher simulator sickness rate for cognitively impaired drivers than for their healthy counterparts. A quantitative relationship between subjective simulator sickness and objective physiological measurements of the central and autonomous nervous systems has been reported by Min, Chung, Min and Sakamoto (Min et al., 2004).

In the past, numerous theories tried to give a better understanding regarding the cause of simulator sickness. The most widely accepted theory – the sensory conflict theory (Reason and Brand, 1975) – assumes a conflict between or within sensory systems responsible for the occurrence of simulator or motion sickness. This is in accordance with more recent studies, which reported a discrepancy between vestibular signals and other, primarily visual, informational inputs in simulator sickness (Kennedy et al., 1993). In contrast, Riccio and Stoffregen (Riccio and Stoffregen, 1991) suppose that congruent information from sensory systems is unusual even in normal everyday tasks. Furthermore, it is assumed that simulator or motion sickness occurs when people are placed in novel environment in which effective ways to maintain balance have not been learned (Duh et al., 2004). Another theory comes from Treisman (Treisman, 1977). The evolutionary theory describes the cause of simulator sickness based on the fact the human species has not had sufficient time to adapt to the relatively new modes of transportation and therefore the body responds to conflicts in sensory information (Money and Cheung, 1983). The Neural Mismatch model – introduced by Reason (Reason, 1978) – describes the existence of a conflict between sensory information and one's own experiences of a motion environment as responsible for the occurrence of simulator or motion sickness.

As reported above, the occurrence of simulator sickness is directly linked to the aspect of adaptation. This becomes also evident in the consideration of studies, which reporting decreased simulator sickness symptoms with repeated exposure within and between days. For example, Domeyer, Cassavaugh and Backs (Domeyer et al., 2013) reported fewer simulator sickness symptoms of participants who experienced a two-day delay between an initial acclimation to the driving simulator. This reduction has been shown to persist up to a month or longer (Hu and Stern, 1999). Within eight trials Mourant, Rengarajan, Cox, Lin, and Jaeger (Mourant et al., 2007) reported an increase in simulator sickness from trial one to five and a decrease from five to eight. Furthermore, the authors pointed out the relevance of the environments used in the simulator.

Based on the previous findings, we hypothesize an effect of the process of aging on the occurrence of simulator sickness, the time of adaptation as well as mental abilities. Gender related differences of the time spent in the simulator are supposed. Regarding the time spent in the simulator, we further assume differences between the group who adapt to the simulator and those who do not.

2 EXPERIMENTAL PROCEDURE

2.1 Participants

In total, 414 people (mean age = 61.69 SD = 12.66 years, ranging from 25 to 89 years, 153 women) participated in the study at hand. All participants have a driving licence and are still actively driving a car. The 20 people aged from 25 to 50 represent a control group compared to the 50+ target group. After a medical check, participants were excluded when they reported neurological or cardio-vascular diseases but also impairments in the ability to see or hear. Furthermore, people above 60 were tested by the *DemTect-Test* and excluded even when they showed first signs of dementia (DemTect$<$9). The study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki. All participants provided written informed consent prior to the experiment and were informed that they could end participation at any time without reprisal.

2.2 Mental Abilities

2.2.1 D2 Test of Attention

The d2 Test is proposed as reliable measure of attention and concentration (Brickenkamp, 1962). The test is a one-page paper-and-pencil test, consisting of 14 rows, each with 47 *p* and *d* characters (Brickenkamp and Zillmer, 1998). The characters have one to four dashes that are configured individually or in pairs above and/or below each letter. Participants are asked to cross out all *d* with two dashes, regardless of whether the dashes are above/below the *d*, or one above and one below the *d*. Thus, a *p* with one or two dashes and a *d* with more or less than two dashes are distracters. For each row the time is limited to 20 seconds in which participants should cancel out as many targets as possible. No pauses are allowed between trials. In agreement with previous studies, (Bates and Lemay, 2004) showed that the d2 Test is an internally consistent and valid measure of visual scanning accuracy and speed.

2.2.2 Trail Making Test (B)

The Trail Making Test (TMT) was originally developed as a component of the Army Individual Test Battery and requires a variety of mental abilities such as cognitive alternation/flexibility, inhibition/interference control, working memory, mental tracking, and attentional set-shifting. Within part B of the TMT, participants should alternately connect 12 letters (A-K) and 13 numbers (1-13) on a page of paper. For example, the first number *1* is followed by the first letter *A*, followed by the second number *2* then second letter *B* and so on. The time for completing the task is recorded. Errors are directly pointed out by the examiners. Therefore, error-correction influences the time to complete a trail (Lezak, 1995). Since its development, the test has been shown as a robust measurement of intelligence (Waldmann et al., 1992), neurological impairments (Reitan and Wolfson, 2004), but also declines related to the process of aging (Wahlin et al., 1996).

2.2.3 Leistungsprüfsystem (German Intelligence Test Battery) LPS-4

The Leistungsprüfsystem was developed by Horn (Horn, 1983) in order to measure individuals' level of intelligence. The LPS-4 is one out of fourteen sub-tests summarized in the Leistungsprüfsystem and measures inferential thinking. Participants are faced with 40 lines of numbers and letters on one page of paper. They are asked to cross out the number or letter that does not fit in the logical order of each line. The difficulty increases from line 1 to line 40. The time to complete the test is limited to eight minutes.

2.3 Driving Simulator

For the determination of the connections between mental performance, age, adaptation time and simulator sickness the static driving simulator of the chair of mechatronics was used. It consists of a close-to-production vehicle of the compact class, which has been extended by force feedback components for the simulation of forces and torques. Among these, in particular, the steering is to be mentioned, which represents one of the most important bi-directional interfaces between driver and vehicle. The simulator is located in a rectangular "cave" (Figure 1) on the ground without a movement platform. The simulated vehicle environment is projected on the caves walls. The field of view of the driver outside the vehicle in this arrangement is 180° and thus includes the entire vehicle front. The side mirrors of the vehicle are represented by screens, which also serve the visual representation of the vehicle environment. In addition, behind the rear window of the vehicle, a monitor is placed, which is used for both the rear view and for the reflection of the image in the interior mirror.

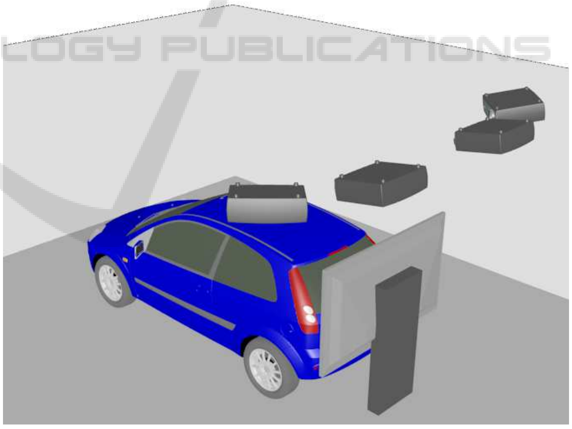

Figure 1: Driving simulator cave.

The driver inputs are read by means of the vehicle CAN bus and used as inputs of a complete vehicle simulation (Maas et al., 2014), which simulates a realistic driving behavior. An electric car is simulated, which results in an automatic gearing and very low noise emissions. Furthermore, road users are represented in the vehicle environment who interact with the simulated (EGO) vehicle (Maas, 2017).

Subjects are therefore in a simulation environment whose usability is physically not different from a series car and thus has a very high degree of reality. The visualization as well as the missing movement of the vehicle on the other hand represent a strong simplification to the reality. Thus, both a high degree of immersion, as well as a sufficient deviation from reality is given, which (as shown above) serves as a possible cause of the simulator sickness.

The presented road scenario (Figure 2) includes an area of 3 x 3 km and consists of inner-city areas, rural routes as well as highways. With a total length of over 70 km, which are merged into several loops, the impression of an infinite scenario without dead-ends is created, which further supports the realistic impression.

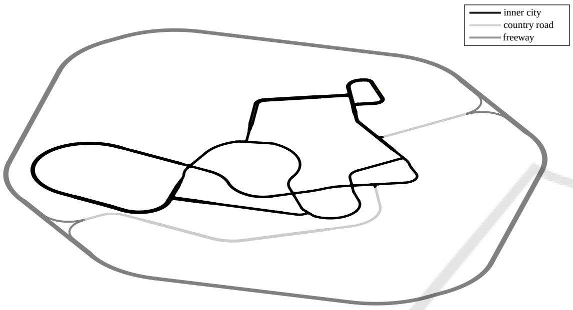

Figure 2: Driving simulator road scenario.

2.4 Procedure

Before starting, participants gave informed consent after carefully reading the instructions. They were informed that they could end participation at any time without reprisal. Afterwards all participants underwent a medical examination with main focus on the suitability for driving in the simulator. Vision and hearing but also cardio-vascular impairments (blood pressure and electrocardiogram) were tested. Furthermore, participants were asked for a history of neurological, psychological, and orthopedic disorders. After the medical examination, participants performed the neuropsychological test battery. People above 60 started with the DemTect-Test. Afterwards all participants completed the identical test sequence starting with the d2 Test for attention and concentration, followed by the Trail Making Test (B), and part four of the Leistungsprüfsystem. Before starting with the driving simulator participants had 5 to 15 minutes to rest. Afterwards, they were instructed to the driving simulator. Participants were informed that they can stop driving at any time in case they feel sick or they want to cancel for another reason. Next to technical instructions (e.g., that it is a vehicle with automatic transmission) participants were asked to choose independently how and where to drive, within the virtual scenario, without following a preceding car or a predefined route. Maximum driving time in the simulator was 25 minutes, as 20 minutes of driving time is planned for the following tests on the subject of assistance systems.

2.5 Data Analysis

Numerous data were recorded during the trip. Using Joshi's algorithm (Joshi et al., 2017), the index of performance (IOP) was calculated from the data. This index contains numerous criteria that provide information on driving performance. The track deviation indicates how precisely the driver manages to drive in the middle of the road. In addition, the steering behavior and activity of the pedals are evaluated. The IOP increases rapidly during unconventional driving, e. g. in the case of permanently large steering movements in order to keep the vehicle on track or alternately pushing the accelerator and brake pedals to their end position. As soon as the participant had adapted the system, the IOP stagnated or decreased (e.g. Figure 3). Otherwise, the IOP continued to rise (e.g. Figure 4). The temporal progressions of the IOPs were calculated from the stored data and examined for gradients. All calculation of IOPs and their gradients were performed automatically with MATLAB and displayed graphically. In order to take into account the distance travelled and the individual traffic situations (traffic, traffic lights, etc.), the determination of the adaptation time was carried out by hand.

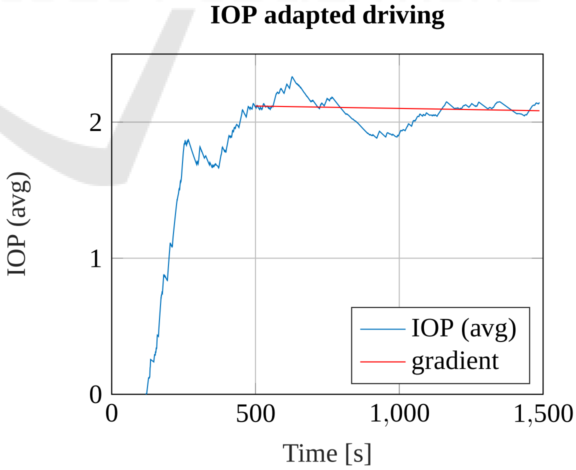

Figure 3: Example average IOP of a well driving participant.

2.6 Statistical Analysis

Statistical analyses were carried out using SPSS Statistics 24.0 for Windows. Homogeneity of variance was tested by using Levene's test. The calcula-

Table 1: Mental ability.

Domain	**Test**		**M**	**SD**	**Range**
Driving simulator	Time within the simulator	[seconds]	1127.5	492.91	19-1716
	Time of adaption	[seconds]	549.97	280.68	53-1205
Mental abilities	D2	[errors]	158.81	40.15	50-284
	TMT (B)	[seconds]	83.29	34.33	28-255
	LPS-4	[number]	25.19	4.14	11-38

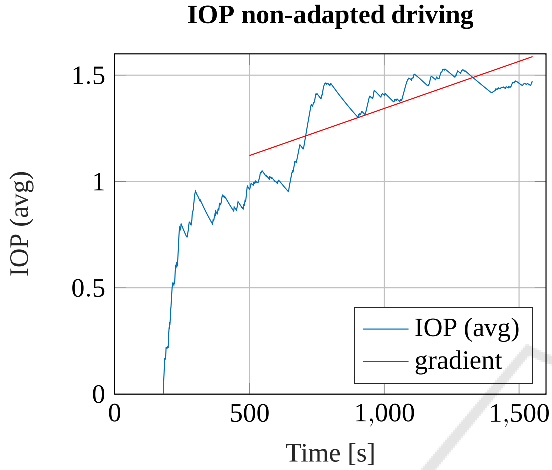
IOP non-adapted driving

Figure 4: Example average IOP of a bad driving participant.

tion of relationships between two variables was made by means of Pearson's correlations. T-test for independent samples was used to investigate gender as well as group (people who adapt to the system vs. not adapt to the system) differences regarding the time spent in the simulator. Effect size was tested by Cohen's d.

3 RESULTS

Results indicated a mean time in the simulator of 1127.5±492.91 seconds, ranging from 19 to 1716 seconds. Ninety participants adapted to the system within an average time of 549.97±280.68 seconds (ranging from 53-1205 seconds). Mental ability was represented by the D2, TMT(B), and LPS-4. D2 show a mean error rate of 158.81±40.15. Participants completed the TMT(B) in 83.29±34.33 seconds and identified 25.19±4.14 errors in the LPS-4 (see Table 1).

Based on a sample size of 414 people (mean age = 61.69 SD = 12.66 years, 153 women), findings revealed significant correlations between age and the time within the simulator as well as mental abilities (tested by the D2, TMT, and LPS-4). No relation was identified between mental abilities and the time spent in the simulator. The single components of mental ability correlated significant with each other (see Table 2). Furthermore, results show a gender-related effect in the occurrence of simulator sickness, by indicating significantly less time in the simulator in women (M = 995.65 seconds SD 510.80) compared to men (M = 1204.79 seconds SD = 466.01) (T(295.4) = 4.152, p <0.001, d = .428).

In most cases of premature abortion, the participants complained of dizziness and nausea. A survey of participants based on Kennedy (Kennedy et al., 1993) with similar modifications to Brooks (Brooks et al., 2010a) was conducted after the study. The results have not yet been fully evaluated. The symptoms did not appear immediately on all participants, but in some cases minutes to hours after the study.

Table 2: Correlations of all participants.

	2	3	4	5
1 Age	-.103*	.351**	.475**	-.387**
2 Time	-	-.054	-.069	.052
3 D2		-	.470**	-.429**
4 TMT			-	-.522**
5 LPS-4				-

$^*p \leq .050$ $\quad$ $^{**}p \leq .010$

Only 90 participants (mean age = 60.36 SD = 14.39 years, ranging from 25 to 89 years) out of the 414 showed an adaptation to the simulator system. Here, results indicate no significant correlation between aging and the time of adaptation. A significant mild correlation is shown between the performance of the D2 and the time of adaptation. Results, regarding mental abilities as well as the relations between single tests for mental ability – as shown in the total sample – are replicated in this smaller sample size (see Table 3).

Table 3: Correlations of participants who have adapted the driving simulator.

	2	3	4	5
1 Age	-.150	.315**	.461**	-.364**
2 Time	-	-.222*	-.051	.009
3 D2		-	.401**	-.352**
4 TMT			-	-.599**
5 LPS-4				-

$^*p \leq .050$ $\quad$ $^{**}p \leq .010$

In addition, people who adapted to the system

(M = 1395.12, SD = 287.90) have spent significantly longer in the simulator compared to those who did not (M = 1053.16, SD = 512.17) (T(259.1) = -8.220, $p < 0.001$, d = .823).

4 CONCLUSIONS

The present study investigated the correlations between mental abilities, age, driving simulator adaption and simulator sickness. Derived from the results, shown in the previous section, it can be stated that:

- Age has an effect on both, mental abilities and probability of simulator sickness occurrences,
- mental abilities do not have a significant effect on simulator sickness occurrences,
- the gender can have an effect on simulator sickness occurrences and
- adapting to the simulator leads to a smaller probability of simulator sickness occurrences.

5 OUTLOOK

Starting from the point of the general influences on simulator sickness described here, further possible parameters can be identified in future work. Among these properties, the properties of the virtual scenario should be taken into account in particular. In this context, it should be investigated to what extent the adaptation to challenging driving tasks correlates with the cognitive workload.

Another challenging option is the consideration of the subjective adaptation time. By determining this parameter, existing algorithms can be extended or replaced by objectifiable methods.

The evaluation and analysis of the questionnaire on symptoms, time, duration and intensity of the simulator sickness promises to provide interesting data for future experiments.

Further tests with a modified simulator provide comparative data and allow systematic improvement of the simulations.

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REFERENCES

Baas, P. H., Charlton, S. G., and Bastin, G. T. (2000). Survey of new zealand truck driver fatigue and fitness for duty. *Transportation Research Part F: Traffic Psychology and Behaviour*, 3(4):185 – 193. Fatigue and Transport (I).

Balk, S. A., Bertola, M. A., and Inman, V. W. (2013). Simulator sickness questionnaire: twenty years later. *Driving Assessment 2013: Proceedings of the 7th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*.

Bates, M. E. and Lemay, E. P. (2004). The d2 test of attention: construct validity and extensions in scoring techniques. *Journal of the International Neuropsychological Society*, 10(3):392–400.

Brickenkamp, R. (1962). *Test d2: Aufmerksamkeits-Belastungs-Test*. Verlag für Psychologie Hogrefe.

Brickenkamp, R. and Zillmer, E. (1998). *The d2 test of attention*. Hogrefe.

Brooks, J. O., Goodenough, R. R., Crisler, M. C., Klein, N. D., Alley, R. L., Koon, B. L., Logan, W. C., Ogle, J. H., Tyrrell, R. A., and Wills, R. F. (2010a). Simulator sickness during driving simulation studies. *Accident Analysis & Prevention*, 42(3):788 – 796. Assessing Safety with Driving Simulators.

Brooks, J. O., Goodenough, R. R., Crisler, M. C., Klein, N. D., Alley, R. L., Koon, B. L., Logan Jr, W. C., Ogle, J. H., Tyrrell, R. A., and Wills, R. F. (2010b). Simulator sickness during driving simulation studies. *Accident Analysis & Prevention*, 42(3):788–796.

Domeyer, J. E., Cassavaugh, N. D., and Backs, R. W. (2013). The use of adaptation to reduce simulator sickness in driving assessment and research. *Accident Analysis & Prevention*, 53:127–132.

Duh, H. B.-L., Parker, D. E., and Furness, T. A. (2004). An independent visual background reduced simulator sickness in a driving simulator. *Presence: Teleoperators & Virtual Environments*, 13(5):578–588.

Freund, B. and Green, T. (2006). Simulator sickness amongst older drivers with and without dementia. *Advances in Transportation Studies*.

Garcia, A., Baldwin, C., and Dworsky, M. (2010). Gender differences in simulator sickness in fixed-versus rotating-base driving simulator. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 54, pages 1551–1555. SAGE Publications Sage CA: Los Angeles, CA.

Horberry, T., Anderson, J., and Regan, M. A. (2006). The possible safety benefits of enhanced road markings: a driving simulator evaluation. *Transportation Research Part F: Traffic Psychology and Behaviour*, 9(1):77–87.

Horn, W. (1983). *Leistungsprüfsystem : L-P-S*. Verl. für Psychologie, Hogrefe, Göttingen [u.a.].

Hu, S. and Stern, R. M. (1999). The retention of adaptation to motion sickness eliciting stimulation. *Aviation, space, and environmental medicine*, 70(8):766–768.

Joshi, S. S., Maas, N., and Schramm, D. (2017). A vehicle dynamics based algorithm for driver evaluation.

In *Intelligent Systems and Control (ISCO), 2017 11th International Conference on*, pages 40–44. IEEE.

Kawano, N., Iwamoto, K., Ebe, K., Aleksic, B., Noda, A., Umegaki, H., Kuzuya, M., Iidaka, T., and Ozaki, N. (2012). Slower adaptation to driving simulator and simulator sickness in older adults aging clinical and experimental research. *Aging clinical and experimental research*, 24(3):285–289.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., and Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology*, 3(3):203–220.

Lewis-Evans, B. and Charlton, S. G. (2006). Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis & Prevention*, 38(3):610–617.

Lezak, M. D. (1995). *Neuropsychological Assessment*. Oxford University Press, USA.

Maas, N. (2017). *Konzeptionierung, Auslegung und Umsetzung von Assistenzfunktionen für die Übergabe der Fahraufgabe aus hochautomatisiertem Fahrbetrieb*. PhD thesis, Universität Duisburg-Essen.

Maas, N., Hesse, B., Koppers, M., and Schramm, D. (2014). Simulator setup according to use case scenarios-a human-oriented method for virtual development. In *Mechatronic and Embedded Systems and Applications (MESA), 2014 IEEE/ASME 10th International Conference on*, pages 1–6. IEEE.

McGehee, D. V., Lee, J. D., Rizzo, M., Dawson, J., and Bateman, K. (2004). Quantitative analysis of steering adaptation on a high performance fixed-base driving simulator. *Transportation Research Part F: Traffic Psychology and Behaviour*, 7(3):181–196.

Min, B.-C., Chung, S.-C., Min, Y.-K., and Sakamoto, K. (2004). Psychophysiological evaluation of simulator sickness evoked by a graphic simulator. *Applied ergonomics*, 35(6):549–556.

Money, K. E. and Cheung, B. S. (1983). Another function of the inner ear: facilitation of the emetic response to poisons. *Aviation, space, and environmental medicine*.

Mourant, R. R., Rengarajan, P., Cox, D., Lin, Y., and Jaeger, B. K. (2007). The effect of driving environments on simulator sickness. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 51, pages 1232–1236. Sage Publications Sage CA: Los Angeles, CA.

Mullen, N. W., Weaver, B., Riendeau, J. A., Morrison, L. E., and Bédard, M. (2010). Driving performance and susceptibility to simulator sickness: Are they related? *American Journal of Occupational Therapy*, 64(2):288–295.

O'Neill, T., Krueger, G., Van Hemel, S., McGowan, A., and Rogers, W. (1999). Effects of cargo loading and unloading on truck driver alertness. *Transportation Research Record: Journal of the Transportation Research Board*, (1686):42–48.

Reason, J. T. (1978). Motion sickness adaptation: a neural mismatch model. *Journal of the Royal Society of Medicine*, 71(11):819.

Reason, J. T. and Brand, J. J. (1975). *Motion sickness*. Academic press.

Reitan, R. M. and Wolfson, D. (2004). The trail making test as an initial screening procedure for neuropsychological impairment in older children. *Archives of Clinical Neuropsychology*, 19(2):281–288.

Riccio, G. E. and Stoffregen, T. A. (1991). An ecological theory of motion sickness and postural instability. *Ecological psychology*, 3(3):195–240.

Rizzo, M., Sheffield, R. A., Stierman, L., and Dawson, J. (2003). Demographic and driving performance factors in simulator adaptation syndrome. *Proceedings of the Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, pages 201–208.

Sahami, S., Jenkins, J., and Sayed, T. (2009). Methodology to analyze adaptation in driving simulators. *Transportation Research Record: Journal of the Transportation Research Board*, (2138):94–101.

Sahami, S. and Sayed, T. (2010). Insight into steering adaptation patterns in a driving simulator. *Transportation Research Record: Journal of the Transportation Research Board*, (2185):33–39.

Stanney, K. M., Kingdon, K. S., and Kennedy, R. S. (2002). Dropouts and aftereffects: examining general accessibility to virtual environment technology. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 46, pages 2114–2118. SAGE Publications Sage CA: Los Angeles, CA.

Takayama, L. and Nass, C. (2008). Driver safety and information from afar: An experimental driving simulator study of wireless vs. in-car information services. *International Journal of Human-Computer Studies*, 66(3):173–184.

Treisman, M. (1977). Motion sickness: an evolutionary hypothesis. *Science*, 197(4302):493–495.

van Winsum, W., De Waard, D., and Brookhuis, K. A. (1999). Lane change manoeuvres and safety margins. *Transportation Research Part F: Traffic Psychology and Behaviour*, 2(3):139–149.

Wahlin, T.-B. R., Bäckman, L., Wahlin, Å., and Winblad, B. (1996). Trail making test performance in a community-based sample of healthy very old adults: effects of age on completion time, but not on accuracy. *Archives of Gerontology and Geriatrics*, 22(1):87–102.

Waldmann, B. W., Dickson, A. L., Monahan, M. C., and Kazelskis, R. (1992). The relationship between intellectual ability and adult performance on the trail making test and the symbol digit modalities test. *Journal of Clinical Psychology*, 48(3):360–363.