Effect of a 30-minute drive in a driving simulator on fatigue, visual attention and driving performance

Tanja BÄRTSCH, Marino MENOZZI

Department of Health Sciences and Technology, ETH Zürich
Scheuchzerstraße 7, Zürich, Switzerland

Abstract. Fatigue impairs driver's attention and performance and can compromise road safety. This study examines the effect of fatigue on a visual attention test. 21 participants drove 30 minutes on a driving simulator in order to get tired and performed the attention test before and after the drive. During the drive, subjective sleepiness, mental workload, and driving performance were recorded. Participants were divided into two groups with different test sequences to assess the effect of time elapsed between the drive and the second attention test. The results revealed that although the 30-minute drive induced fatigue, effects of fatigue on visual attention are ambiguous. Moreover, the test sequences had no effect. However, this study provides information on the sensitivity of the attention test and how the test might be adapted to detect fatigue and thus, improve road safety.

Keywords: Fatigue, visual attention, driving performance, driving simulator

1. Introduction

Fatigue is severely affecting driving skills and belongs to the major causes of traffic accidents (ERSO, 2018). Driving while fatigue limits the ability to drive, such as maintaining the following distance, speed or lane position (Akerstedt et al., 2005; Ting et al., 2008), and impairs visual attention, a function, which is important in order to perceive what is happening in the environment (Jackson et al., 2013). Therefore, drivers should refrain from driving in case of excessive fatigue. However, the high estimated rate of fatigue-related accidents underlines the severity of the lack of road safety in relation to fatigued driving. One way to improve road safety would be if the police were able to identify overtired drivers during road traffic controls. In contrast to assessing driving under influence of drugs (abusive or medical) and alcohol, there is a lack of objective, rapid measurement techniques, which can be used considering the organizational and legal situation in police traffic controls.

Our previously developed test for recording attentional performance (Menozzi et al., 2012) could fit requirements of police traffic controls, as it is performed in a short duration (4 min) and it is not invasive. The test is about detecting a signal, which appears either in the left, central, or right visual field. Considering previous studies, we have good reasons to believe that data recorded in people with fatigue, are affected in a particular manner. Faber et al. (2012) showed that attention was affected by fatigue, in the form of a decreased ability to suppress irrelevant information, which resulted in decreased response accuracies. Moreover, a dominance of right hemisphere for visuospatial attention has been demonstrated (Heilman et al., 2000; Heilman & Van Den Abell, 1980). In addition, functional magnetic resonance imaging studies revealed that there is a substantial overlap between alertness network and visuospatial orienting network within the right brain hemisphere, leading to the strong believe that adverse factors, which impair the alertness, may also affect the visuospatial attention (Fernandez-Duque & Posner, 2001; Shulman et al., 2010). Therefore, fatigue, leading to a reduced level of alertness, is assumed to cause a rightward shift in attention, which is characterized by, for instance, slower reaction times and omission of stimuli appearing in the left visual field (Benwell et al., 2013).

In this study, we investigate how the attention performance change after a 30-minute drive, which aims to induce fatigue in participants. Based on the dominant theoretical framework postulating rightward shift in attention with declining alertness, we expect that the detectability of the signal and the reaction time to the signal is better in the right visual field compared to the left visual field when the participants are tired.

2. Method

A total of 21 participants (13 m, 7 f) possessing valid driving license were recruited. Age ranged from 19 y to 43 y with a mean of 27.75 y (standard deviation [SD] 4.96 y).

Participants drove 30 minutes in our driving simulator on an oval shaped track with little traffic and a monotone environment. They were instructed to follow the car ahead at a constant distance. The fatigue level over the 30-minute drive was measured by the subjective Karolinska Sleepiness Scale (Akerstedt et al., 2005). Since mental workload has been shown to lower attentional performance, the mental workload during the driving task was recorded by using the Instantaneous Self Assessment (ISA) scale (Hering & Coatleven, 1996). During the drive, all 5 minutes the KSS and ISA were administered on the screen of the driving simulator and the participant responded verbally to the questionnaires. While the scales were presented, the autopilot was enabled and as soon as the participant have pressed a button on the steering wheel, the scales disappeared, and the autopilot was disabled again. Furthermore, driving in a driving simulator could be perceived as unnatural and could also cause cybersickness both of which possibly affecting attention. Therefore, it was necessary to control for effects of the presence, meaning the feeling of being there, and cybersickness. The questionnaire of Witmer et al. (1998) was used to record the presence, and the Cyber Sickness Questionnaire (SSQ) (Kennedy et al., 1993) was used for recording cybersickness.

Besides recording KSS, objective measures of sleepiness were recorded by measuring the standard deviation of the lateral position of the car, of the headway to the front car, and of the car speed during the 30-minute drive. To measure the attention performance, the visual attention test of Menozzi et al. (2012) was used. It is a computerized test, in that participants report whether a flashed 6-digit number appearing on a background movie, showing a car drive, includes the digit “3”. The number appeared either on the left, central, or right visual field. Using the theory of signal detection (Gescheider GA, 1997), fractions of hits and false alarms are combined to the so called detectability d’. d’ and the reaction time were recorded for each trial.

Assuming the traffic police will use this visual attention test in traffic controls, it is important to know whether the test should be performed immediately after a driver has been stopped or at the end of the usual traffic control. For this purpose, participants were randomly divided into two groups that differed in the test sequence (see Figure 1). To imitate the time passed during a police control, 10 participants conducted the second visual attention test after having answered the PQ and the SSQ, whereas the other group included 11 participants performed the PQ and SSQ after the second visual attention test.

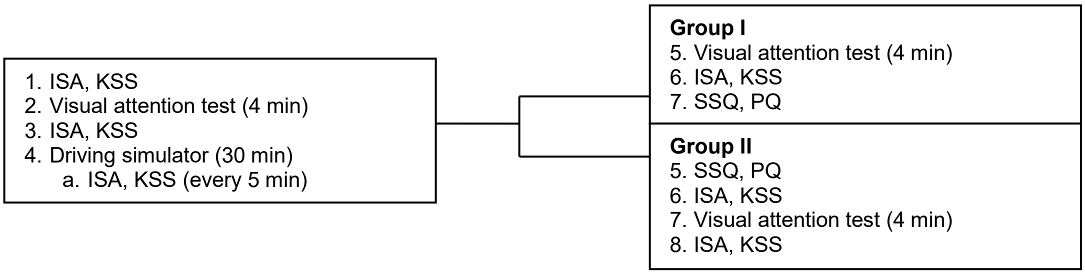

Figure 1. *Overview of the study procedure.*

3. Results

3.1 Changes in subjective sleepiness and mental workload

The subjective sleepiness level increased over the 30-minute drive [Friedman test: $\chi^2(5) = 60.786$, $p < 0.01$, n=21)] (Figure 2). At the end of the drive the KSS scores significantly higher than at the beginning of the drive (difference =2.53, z=-3.476, $p_{adjusted}<0.01$, r=0.76) and the participants significantly felt more sleepy before the second attention test (M=6.5) than before the first test (M=5) (Sign test: p<0.01, n=21). The ISA score did not change over time [Friedman test: $\chi2(5) = 7.846$, p=0.165, n=21)].

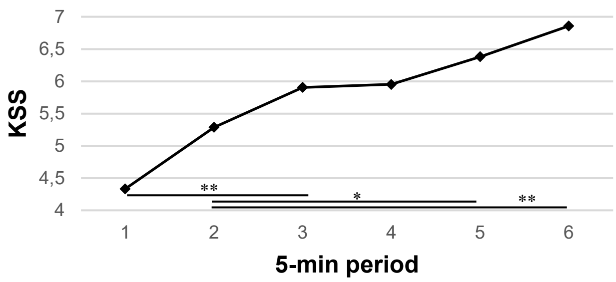

Figure 2. *Mean of KSS as a function of driving time (period 1-6). The horizontal bars indicate the periods between which the KSS level increased significantly. Significance of difference (Friedman test, post hoc test: Dunn-Bonferroni test): *: p<0.05, **: p<0.001.*

3.2 Progressive Variation of driving performance

Data of two subjects were excluded due to technical problems during the driving task. One-way repeated ANOVA with the time-on-task separated into six 5-min periods revealed that the standard deviation of lateral position varied significantly with driving time [$F(5,90)=3.696$, $p<0.01$, $\eta^2=0.170$]. The post-hoc analyses, for which Bonferroni-corrected pairwise comparisons were performed, showed that the variation of the lateral position (p=0.05) increased significantly after 20 minutes (M=0.632, SD= 0.051) compared to the first 5-minute period of the experiment (M=0.535, SD= 0.05). The variation of the lateral position correlated with the subjective sleepiness level [$r_s=0.200$, p=0.038, $\eta^2=108$], but according to Cohen (1992), the effect is considered as weak.

The standard deviation of headway (p=0.824) and the standard deviation of car speed (p=0.828) did not significantly vary with driving time.

Analysing the driving performance on the curved and straight roads separately, a significant change in lateral position over time could be observed only on the straight road sections [$F(5,90)=3.810$, $p< 0.01$, $\eta^2=0.175$].

3.3 Attention performance

Data of two participants were excluded due to many missed responses in the visual attention test (n=19). A three-way ANOVA considering the factors location of presentation of the six-digit number in the visual field (two levels, centre/periphery) and time (two levels, before/after the drive) as within subject factors, and group as a two level (Group 1/Group 2) between subject factor was run in order to compare effects on d' and RT. The results showed no significant effect of time on d' (p=0.552) and RT (p=0.263). The independent variable group had no significant effect on d' (p=0.744) and RT (p=0.824). But there was a significant main effect of the location of presentation of the six-digit number on the detectability d' [$F(1,16)=8.081$, $p=0.012$, $\eta^2=0.336$]. The detectability was significant higher in the central visual field (M=3.046, SD=0.075) than in the periphery (M=2.787, SD=0.132). The same applies to the reaction time [$F(1,16)=88.956$, $p<0.01$, $\eta^2=0.848$]. The reaction time was significant faster in the central visual field (M=693.258, SD=13.095) than in the periphery (M=812.775, SD=16.302). The post-hoc test of a further three-way ANOVA (3x2x2), in that the effect of the left, central and right visual field was investigated, revealed that there was no difference of the attention performance in the left and right visual field (d': p= 0.073; RT: p= 1.000). There was a tendency that the detectability in the right visual field (M=2.481, SD=0.121) was lower than in the left visual field (M=2.772, SD=0.113), p=0.073 (Figure 2).

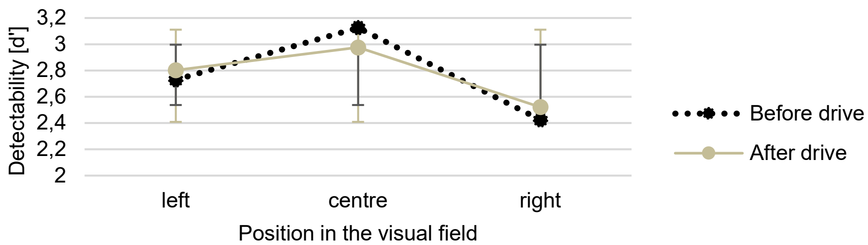

Figure 3. *Average and one standard deviation of d' for the task carried out in the left, central and right visual field before (dashed line) and after (solid line) the 30-minute drive. For more clarity, the scale starts at d'=2.*

In addition, the first and last third of the attention test were analysed separately. Even if there were no significant findings, it is worth noting that regarding the left visual field in the last third, 13 of the 19 participants showed a lower d' in the second attention test compared to the first attention test. In average, d' decreased by 0.5.

4. Discussion

The results indicate that a 30-minute drive on a low-traffic road and in a monotonous environment on a driving simulator is a fatigue factor, manifested through increased KSS values and increased lateral movements of the car over time. The effect of fatigue on the driving behaviour is most noticeable on straight road sections, which is consistent with Desmond's (1998) findings. Regarding the headway and velocity, no significant variations were observed, which may be due to the study design. As the driving behaviour of the autopilot most likely did not match that of the participant, they had to adjust the driving behaviour back by their own after the autopilot has deactivated. This might have biased the data.

Furthermore, the ISA values did not increase over time probably since the work demands during the performance of the task remain the same over time.

As expected from many previous literature (e.g., Crundall et al., 2002), the detectability and reaction time is better for central signals than for peripheral signals. However, the hypotheses that with increased fatigue, the detectability and reaction time generally deteriorate and are better in the right visual field than in the left could not be verified. There is even a tendency that the detectability is better in the left than in the right visual field, which indicates the so-called pseudo-neglect. This is a phenomenon that refers to the tendency to direct attention more to the left than to the right (Manly et al., 2005). However, the results indicate that the effect of fatigue might be seen in the last third of the attention test. An explanation could be that attention decreases with time or the background of the test is most complex in the last third, and thus more attention is required.

One reason for the lack of significant effect of fatigue on visual attention might be that the attention test is not sensitive enough to detect a small change in fatigue, which was on average 1.5 in the KSS scale. To improve the sensitivity, the difficulty level of the test could be increased by a shorter target presentation duration which would lower test performance scores (Huang et al., 2019). Another reason could be that the participants are between 19 and 43 years old, and that the effect of fatigue does not affect attention as much as it would in an older population. Menozzi et al. (2012) showed that the performance in the central visual field did not depend on age, whereas the detectability in the periphery was shown to be an inverted U-shape function of age peaking in the fourth decade of lifespan. The visual attention performance might decrease in people older than 50 years compared to people between 20 and 50 since the psychomotor and cognitive performance decreases (Davies et al., 1992). In addition, it was shown that inhibitory performance is an inverted U-shape function of age (Menozzi et al., 2012). Based on those facts and the assumption that fatigue reduces the ability to suppress irrelevant information (Faber et al., 2012), we hypothesize that the effect of fatigue on visual attention may have a more significant effect in people over 50 years of age than the effect in a younger population.

Furthermore, the results revealed that it does not matter whether the attention test is performed immediately after a drive or a few minutes later. Regarding road traffic controls, this would mean that the police can apply the test directly after a driver has stopped or after the traffic control procedure.

Conclusively, this study verified the 30-minute drive on the driving simulator as a fatigue-inducing method. This study showed that the visual attention test is not sensitive enough to detect small changes in subjective sleepiness levels. However, by making the test more difficult, the sensitivity for fatigue might be increased.

5. References

Akerstedt, T., Peters, B., Anund, A., & Kecklund, G. (2005). Impaired alertness and performance driving home from the night shift: a driving simulator study. *Journal of Sleep Research*, *14*(1), 17–20. https://doi.org/10.1111/j.1365-2869.2004.00437.x

Benwell, C. S. Y., Thut, G., Learmonth, G., & Harvey, M. (2013). Spatial attention: Differential shifts in pseudoneglect direction with time-on-task and initial bias support the idea of observer subtypes. *Neuropsychologia*, *51*(13), 2747–2756. https://doi.org/10.1016/j.neuropsychologia.2013.09.030

Crundall, D., Underwood, G., & Chapman, P. (2002). Attending to the peripheral world while driving. *Applied Cognitive Psychology*, *16*(4), 459–475. https://doi.org/10.1002/acp.806

Davies, D. R., Taylor, A., & Dorn, L. (1992). Aging and human performance. In *Handbook of human performance* (Vol. 3, pp. 25–61). Academic Press.

Desmond, P. A. (1998). Driver fatigue: performance and state. *L. Hartley (Red.) Managing Fatigue in Transportation. Oxford, Elsevier Science*, 65–76.

ERSO. (2018). *Fatigue*. https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/ersosynthesis2018-fatigue.pdf

Faber, L. G., Maurits, N. M., & Lorist, M. M. (2012). Mental Fatigue Affects Visual Selective Attention. *PLoS ONE*, *7*(10), 48073. https://doi.org/10.1371/journal.pone.0048073

Fernandez-Duque, D., & Posner, M. I. (2001). Brain imaging of attentional networks in normal and pathological states. In *Journal of Clinical and Experimental Neuropsychology* (Vol. 23, Issue 1, pp. 74–93). J Clin Exp Neuropsychol. https://doi.org/10.1076/jcen.23.1.74.1217

Gescheider GA (Ed.). (1997). *Psychophysics: method and theory* (3rd ed.).

Heilman, K. M., Valenstein, E., & Watson, R. T. (2000). Neglect and related disorders. In *Seminars in Neurology* (Vol. 20, Issue 4, pp. 463–470). Semin Neurol. https://doi.org/10.1055/s-2000-13179

Heilman, K. M., & Van Den Abell, T. (1980). Right hemisphere dominance for attention: The mechanism underlying hemispheric asymmetries of inattention (neglect). *Neurology*, *30*(3), 327–330. https://doi.org/10.1212/wnl.30.3.327

Hering, H., & Coatleven, G. (1996). ERGO (version 2) for instantaneous self assessment of workload in a real-time ATC simulation environment. *EEC Note No.10/96*.

Huang, Y.-Y., Menozzi, M., & Favey, C. (2019). A screening tool for occupations requiring a high level of attentional performance. *International Journal of Industrial Ergonomics*, *72*, 86–92. https://doi.org/10.1016/j.ergon.2019.04.005

Jackson, M. L., Croft, R. J., Kennedy, G. A., Owens, K., & Howard, M. E. (2013). Cognitive components of simulated driving performance: Sleep loss effects and predictors. *Accident Analysis and Prevention*, *50*, 438–444. https://doi.org/10.1016/j.aap.2012.05.020

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology*, *3*(3), 203–220. https://doi.org/10.1207/s15327108ijap0303_3

Manly, T., Dobler, V. B., Dodds, C. M., & George, M. A. (2005). Rightward shift in spatial awareness with declining alertness. *Neuropsychologia*, *43*(12), 1721–1728. https://doi.org/10.1016/j.neuropsychologia.2005.02.009

Menozzi, M., Baumer-Bergande, E., & Seiffert, B. (2012). Working towards a test for screening visual skills in a complex visual environment. *Ergonomics*, *55*(11), 1331–1339. https://doi.org/10.1080/00140139.2012.715680

Shulman, G. L., Pope, D. L. W., Astafiev, S. V., McAvoy, M. P., Snyder, A. Z., & Corbetta, M. (2010). Right hemisphere dominance during spatial selective attention and target detection occurs outside the dorsal frontoparietal network. *Journal of Neuroscience*, *30*(10), 3640–3651. https://doi.org/10.1523/JNEUROSCI.4085-09.2010

Ting, P.-H., Hwang, J.-R., Doong, J.-L., & Jeng, M.-C. (2008). Driver fatigue and highway driving: a simulator study. *Physiology & Behavior*, *94*(3), 448–453. https://doi.org/10.1016/j.physbeh.2008.02.015

Witmer, B. G., & Singer, M. J. (1998). Measuring Presence in Virtual Environments: A Presence Questionnaire. In *Presence* (Vol. 7, Issue 3).

Acknowledgement. The authors are very much in debt to Jiahui An from Tübingen University (Graduate Training Centre of Neuroscience) for collecting the data.

Gesellschaft für
Arbeitswissenschaft e.V.

Arbeit HUMAINE gestalten

67. Kongress der
Gesellschaft für Arbeitswissenschaft

Lehrstuhl Wirtschaftspsychologie (WiPs)
Ruhr-Universität Bochum

Institut für Arbeitswissenschaft (IAW)
Ruhr-Universität Bochum

3. - 5. März 2021

GfA-Press

Bericht zum 67. Arbeitswissenschaftlichen Kongress vom 3. - 5. März 2021

Lehrstuhl Wirtschaftspsychologie, Ruhr-Universität Bochum
Institut für Arbeitswissenschaft, Ruhr-Universität Bochum

Herausgegeben von der Gesellschaft für Arbeitswissenschaft e.V.
Dortmund: GfA-Press, 2021
ISBN 978-3-936804-29-4

NE: Gesellschaft für Arbeitswissenschaft: Jahresdokumentation

Als Manuskript zusammengestellt. Diese Jahresdokumentation ist nur in der Geschäftsstelle erhältlich.

Schriftleitung: Matthias Jäger
im Auftrag der Gesellschaft für Arbeitswissenschaft e.V.

Screen design und Umsetzung
© 2021 fröse multimedia, Frank Fröse
office@internetkundenservice.de · www.internetkundenservice.de