How younger and older drivers' steering reversals change with cognitive distraction during day and night-time driving

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Abstract: Distracted driving is known to contribute to undesirable driving outcomes, including near misses and crashes. While the adverse effects of driver distraction are well recognised, the modality of distraction and individual and environmental factors also matter. With this in mind, this study explored how age, lighting conditions, a Detection-Response Task (DRT) and cognitive load affect vehicle control, investigating the effects of steering wheel reversal rate (SWRR). A driving simulator study was conducted with 20 younger (M_{Age} = 22.60, SD_{Age} = 1.22) and 17 older (M_{Age} = 65.82, SD_{Age} = 3.78) drivers. Drivers completed two experimental drives (day-time and night-time), during which they were also required to complete the n-back and DRT tasks. The effect of these conditions on SWRR was examined separately for both 0.5° and 2.5° reversals. Results show an inverse change in night-time driving for both small and large reversal rates, with an increase for older drivers and a decrease for younger drivers compared to day-time driving. In addition, cognitive load was associated with fewer large reversals in the absence of DRT, whereas the presence of DRT resulted in an increase in both small and large steering reversals. The findings enhance our understanding of how driver distraction and other individual and environmental factors affect steering control.

1. Introduction

Numerous studies (Caird et al., 2018; Lipovac et al., 2017) have explored the detrimental impacts of driver distraction on traffic safety. Driver distraction involves visual, manual, auditory, vocal, and cognitive elements, which can also be combined (Foley et al., 2013). Markkula and Engström (2006) state that visual and cognitive loads (or distractions) influence steering through the steering wheel reversal rate: cognitive load prompts micro corrections, while visual load (e.g., drivers briefly taking eyes off the road) results in larger corrections. However, human behaviour in driving is influenced by a range of factors, including age (Horberry et al., 2006), driving style (Rong et al., 2011), and lighting conditions (Wood, 2020). Moreover, the combined effects of these factors can further impact driving performance.

Expanding on prior research on secondary task effects on SWRR (Kountouriotis et al., 2016) and Öztürk et al.'s (2023) findings, this study explores the influence of age, lighting, DRT engagement, and cognitive load on SWRR. To account for drivers' individual differences, we employ multilevel modelling.

2. Method

2.1 Participants and Design

The study involved 37 participants (20 younger: M_{Age} = 22.60, SD_{Age} = 1.22; 17 older: M_{Age} = 65.82, SD_{Age} = 3.78) with 10 younger and five older drivers being females. The study design was a 3 (cognitive task: no task, 1-back, 2-back) x 2 (lighting: day-time, night-time) x 2 (DRT: with DRT, without DRT) x 2 (age: younger, older) mixed factors design, with age as the only between-participant factor.

2.2 Cognitive Task

Participants performed an auditory n-back task (Mehler et al., 2011) with two difficulty levels (1-back, 2-back). In each ~30-second block, participants heard a random list of 10 digits at 2.25 s intervals, presented through the car's speakers. Participants repeated the digit before (1 back) or two before (2 back) the last one heard.

2.3 Detection-Response Task

Following the same procedure as Merat and Jamson (2008), a visual DRT measured the effects of a secondary task (here, n-back task) on driving performance. Following the ISO (2016) guidelines, the stimuli (a red circle) appeared randomly on the driving scene, presented every 3–5 seconds, remaining on the screen for one second. The circles were presented to the left or right of the driving scene at a vertical angle of 11° to 23° (from the forward viewpoint of drivers) and a horizontal area of 2° to 4° above the horizon. Participants were asked to look ahead, as the circles were visible in the peripheral vision. They pressed a button on the steering wheel as soon as they saw the stimuli. Each DRT block matched the n-back block duration (~30 s) and contained 7–9 stimuli.

2.4 Procedure

The study was approved by the University of Leeds ethics committee (AREA 21-108). On arrival, participants received information and consent forms. First, participants practised the n-back and DRT tasks without driving, followed by practising driving in the simulator with a period of DRT and DRT plus 2-back task. For the main experiment, participants completed two drives with one of the two lighting conditions (counterbalanced). Each drive consisted of sections of 1-back, 2-back, DRT, DRT plus 1-back, and DRT plus 2-back on straight sections of a rural road. Participants received £20 compensation after completing the study (cf. Öztürk et al., 2023).

Table 1: Multilevel model predicting small reversals

Names	Effect	Estimate	SE	95% Confidence Interval Lower	Upper	t	p
(Intercept)	(Intercept)	28.81	1.23	26.40	31.21	23.46	< .001
DRT	DRT present - No DRT	0.48	0.31	-0.12	1.07	1.55	0.121
Lighting	Day - Night	-0.56	0.28	-1.12	-0.00	-1.98	0.047
Age group	Older - Younger	1.91	2.45	-2.90	6.71	0.78	0.442
N-back 1	1-back - No n-back task	1.57	0.37	0.85	2.29	4.28	< .001
N-back 2	2-back - No n-back task	2.45	0.37	1.73	3.17	6.66	< .001
Lightning * Age group	Night – Day * Older – Younger	3.94	0.57	2.82	5.05	6.94	< .001
DRT * N-back 1	DRT present - No DRT * 1-back - No n-back task	4.67	0.74	3.22	6.11	6.35	< .001
DRT * N-back 2	DRT present - No DRT * 2-back - No n-back task	4.08	0.74	2.64	5.52	5.55	< .001

2.5 *Analysis*

SWRR was calculated for 0.5° and 2.5° reversals per minute, using Markkula and Engström's (2006) syntax. The 0.5° SWRR was conceptualised as small (micro) reversals, and 2.5° SWRR as large reversals (Kountouriotis et al., 2016). In the models, fixed factors include age group (younger, older), lighting (day, night), n-back task (no n-back, 1-back, 2-back), and DRT (not present, present), with each subject as a random effect. MATLAB R2020a was used for the data extraction and Jamovi 2.3.28.0 for the analysis.

3. Results

3.1 *Small Reversals – 0.5°*

Model fit (Log Likelihood) was -4148.4428. The model's explanatory power was notable (conditional R^2 = 0.69 and marginal R^2 = 0.05). Significant main effects (see Table 1) were observed for lighting (p = .047, with night-time diminishing micro-SWRR) and n-back (p < .001, 1-back and 2-back increasing micro-SWRRs compared to no n-back).

Significant interactions were found between lighting and age (p < .001) as well as DRT and n-back tasks (p < .001). Compared to day-time, older drivers showed an increase (p = .005), and younger drivers showed a decrease (p < .001) in small reversals during night-time (Figure 1).

When examining the transition from no n-back task to the 1-back task under both DRT conditions, the interaction differed (Figure 2): in the absence of DRT, there was a decrease in micro-SWRR from the no n-back condition to the 1-back condition (non-significant); while in the presence of DRT, SWRR showed a significant increase. Final model's ICC was 67.2%.

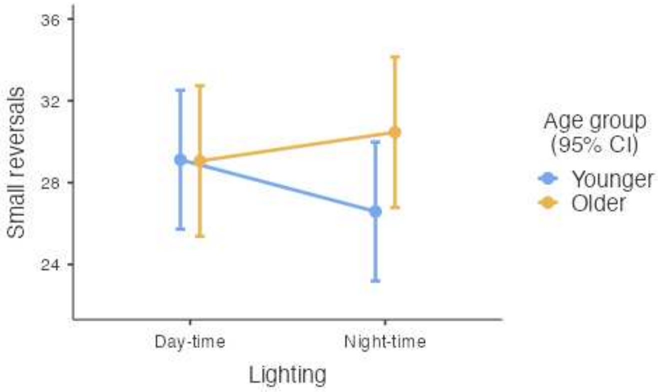

Figure 1: Interaction of lighting and age

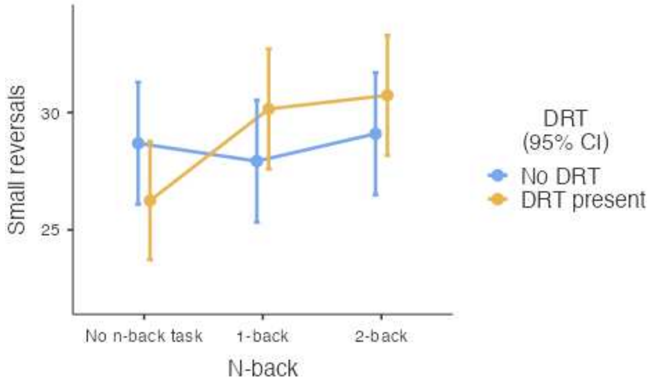

Figure 2: Interaction of n-back tasks and DRT

3.2 *Large Reversals – 2.5°*

Model fit was -3168.6467 with conditional R^2 = 0.48 and marginal R^2 = 0.04. Significant main effects (see Table 2) were observed for n-back (p = .014, 1-back decreasing large SWRRs) and DRT (p = .014, presence of DRT increasing large SWRRs).

Table 2: Model predicting large reversals

Names	Effect	Estimate	SE	95% Confidence Interval Lower	Upper	t	p
(Intercept)	(Intercept)	2.47	0.39	1.71	3.22	6.41	< .001
DRT	DRT present - No DRT	0.36	0.15	0.07	0.65	2.46	0.014
Lighting	Night - Day	-0.20	0.14	-0.47	0.06	-1.49	0.137
Age group	Older - Younger	0.75	0.77	-0.76	2.26	0.98	0.335
N-back 1	1-back - No n-back task	-0.52	0.18	-0.87	-0.17	-2.93	0.003
N-back 2	2-back - No n-back task	-0.22	0.18	-0.57	0.13	-1.24	0.217
Lighting1 ✻ Age group1	Night - Day ✻ Older - Younger	0.87	0.27	0.34	1.41	3.19	0.001
DRT ✻ N-back 1	DRT present - No DRT ✻ 1-back - No n-back task	2.88	0.36	2.18	3.57	8.11	< .001
DRT ✻ N-back 2	DRT present - No DRT ✻ 2-back - No n-back task	2.11	0.36	1.42	2.81	5.96	< .001

Again, interactions were found between lighting and age ($p = .001$) as well as DRT and n-back tasks ($p < .001$). As with small reversals, night-time increased large reversals for older drivers and decreased them for younger drivers (Figure 3). The interaction (Figure 4) between n-back tasks and DRT was similar to that in the small reversals model. Final model's ICC was 45.9%.

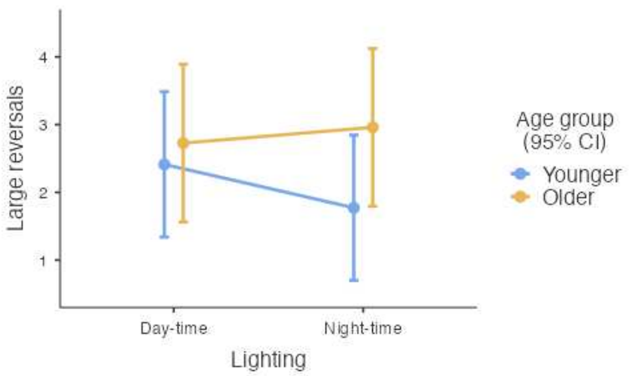

Figure 3: Interaction of lighting and age

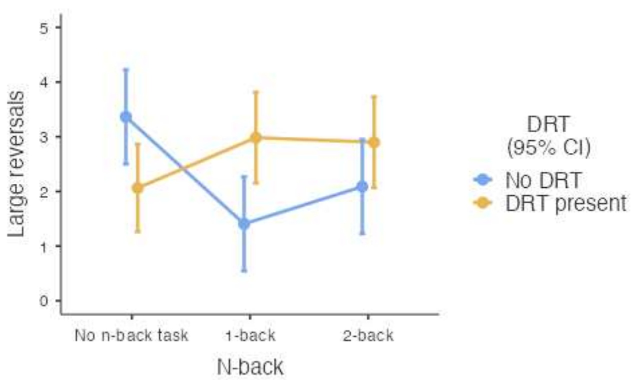

Figure 4: Interaction of n-back tasks and DRT

4. Discussion

This study investigated the effect of a number of human and environmental factors on SWRR. Without DRT, small reversals were at about the same level with increased cognitive load, but there was a significant reduction in large reversals for both the 1-back and 2-back conditions. Also, in line with Kountouriotis et al. (2016), SWRRs increased with cognitive load. For example, the increase in 2-back (compared to 1-back) might reflect the change with the increased task difficulty.

Furthermore, similar to Kountouriotis et al. (2016), larger steering wheel reversals were observed with DRT, a visual task. Despite instructions advising 'not to look (search) for the visual stimuli', the presence of the peripheral task resulted in drivers making more large reversals than when driving without DRT.

The presence of a visual task had a strong effect on large SWRRs, effectively counteracting the reduction in large reversals due to increased cognitive load. The DRT effect aligns with the Active Gaze Model (Wilkie et al., 2008), indicating that tasks diverting eyes from the road centre may result in an increase in larger steering reversals.

Previous research indicates that individual differences affect in-car glance durations (Broström et al., 2013; 2016; Grahn et al., 2023) and occlusion times (Grahn & Taipalus, 2021; Grahn et al., 2023). Here, high ICC values indicate that SWRR variability also arises from individual differences rather than random variation within subjects.

5. Conclusions

SWRR appears to be sensitive to individual and environmental factors as well as to different levels of cognitive load. Furthermore, the effect of visual and cognitive tasks on SWRR varies and warrants further investigation. The models also showed a large effect of individual variability in SWRR. Finally, the findings have implications for the relationship between driver distraction and driver behaviour. The change in the reversal rate of younger and older drivers during night-time driving is particularly important for road safety to understand differences in behavioural adaptation to reduced visibility during night-time driving.

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 The data are available on request from the second author (I.O., i.ozturk@leeds.ac.uk).

References

Broström, R., Aust, M. L., Wahlberg, L., & Källgren, L. (2013). What drives off-road glance durations during multitasking – capacity, practice or strategy? Proceedings on the 3rd International Conference on Driver Distraction and Inattention.

Broström, R., Bengtsson, P., & Aust, M. L. (2016). Individual glance strategies and their effect on the NHTSA visual manual distraction test. *Transportation Research Part F: Traffic Psychology and Behaviour, 36,* 83–91. https://doi.org/10.1016/J.TRF.2015.10.017

Caird, J. K., Simmons, S. M., Wiley, K., Johnston, K. A., & Horrey, W. J. (2018). Does talking on a cell phone, with a passenger, or dialing affect driving performance? An updated systematic review and meta-analysis of experimental studies. *Human Factors, 60*(1), 101–133. https://doi.org/10.1177/0018720817748145

Foley, J. P., Young, R., Angell, L., & Domeyer, J. E. (2013, June). Towards operationalizing driver distraction. In *Driving Assessment Conference* (Vol. 7, No. 2013). University of Iowa.

Grahn, H., & Taipalus, T. (2021). Refining distraction potential testing guidelines by considering differences in glancing behavior. *Transportation Research Part F: Traffic Psychology and Behaviour, 79,* 23–34. https://doi.org/10.1016/j.trf.2021.03.009

Grahn, H., Kujala, T., Taipalus, T., Lee, J., & Lee, J. D. (2023). On the relationship between occlusion times and in-car glance durations in simulated driving. *Accident Analysis and Prevention, 182,* 106955. https://doi.org/10.1016/j.aap.2023.106955

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention, 38*(1), 185–191. https://doi.org/10.1016/j.aap.2005.09.007

International Organisation for Standardisation (ISO) (2016). ISO 17488:2016 – *Road vehicles - Transport information and control systems - Detection-response task (DRT) for assessing attentional effects of cognitive load in driving. International Organization for Standardization*. https://www.iso.org/standard/59887.html

Kountouriotis, G. K., Spyridakos, P., Carsten, O. M., & Merat, N. (2016). Identifying cognitive distraction using steering wheel reversal rates. *Accident Analysis & Prevention*, *96*, 39–45. https://doi.org/10.1016/j.aap.2016.07.032

Lipovac, K., Đerić, M., Tešić, M., Andrić, Z., & Marić, B. (2017). Mobile phone use while driving-literary review. *Transportation Research Part F: Traffic Psychology and Behaviour, 47,* 132–142. https://doi.org/10.1016/j.trf.2017.04.015

Markkula,G., & Engström, J. (2006). A steering wheel reversal rate metric for assessing effects of visual and cognitive secondary task load. In Proceedings of the *13th ITS World Congress*. Leeds.

Mehler, B., Reimer, B., & Dusek, J.A. (2011). *MIT AgeLab delayed digit recall task (n-back).* MIT AgeLab White Paper Number 2011–3B. Massachusetts Institute of Technology, Cambridge, MA. http://web.mit.edu/reimer/www/pdfs/Mehler_et_al_n-back-white-paper_2011_B.pdf

Merat, N., & Jamson, A. H. (2008). The Effect of Stimulus Modality on Signal Detection: Implications for Assessing the Safety of In-Vehicle Technology. *Human Factors, 50*(1), 145–158. https://doi.org/10.1518/001872008X250656

Öztürk, İ., Merat, N., Rowe, R., & Fotios, S. (2023). The effect of cognitive load on Detection-Response Task (DRT) performance during day- and night-time driving: A driving simulator study with young and older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 97,* 155–169. https://doi.org/10.1016/j.trf.2023.07.002

Rong, J., Mao, K., & Ma, J. (2011). Effects of individual differences on driving behavior and traffic flow characteristics. *Transportation Research Record: Journal of the Transportation Research Board, 2248*(1), 1–9. https://doi.org/10.3141/2248-01

Wilkie, R. M., Wann, J. P., & Allison, R. S. (2008). Active gaze, visual look-ahead, and locomotor control. *Journal of Experimental Psychology: Human Perception and Performance, 34*(5), 1150–1164. https://doi.org/10.1037/0096-1523.34.5.1150

Wood, J. M. (2020). Nighttime driving: visual, lighting and visibility challenges. Ophthalmic and *Physiological Optics, 40*(2), 187–201. https://doi.org/10.1111/opo.12659