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The Effect of a Simulated Hearing Loss on Performance of an Auditory Memory Task in Driving

Nicholas Herbert[a], Nicholas Thyer[b], Sarah Isherwood[b], Natasha Merat[a]

[a] Institute for Transport Studies, University of Leeds, UK

[b] School of Medicine, University of Leeds, UK

Corresponding author: Nicholas Herbert, Institute for Transport Studies, 36-40 University Road, University of Leeds, Leeds, LS2 9JT. E-mail: hc06nch@leeds.ac.uk.

Abstract: Hearing loss has been shown to exacerbate the effect of auditory distraction on driving performance in older drivers. This study controlled for the potentially confounding factor of age-related cognitive decrements, by applying a simulated hearing loss in young, normally hearing individuals. Participants drove a simulated road whilst completing auditory tasks under simulated hearing loss or normal hearing conditions. Measures of vehicle control, eye movements and auditory task performance were recorded. Results showed that performing the auditory tasks whilst driving resulted in more stable lateral vehicle control and a reduction in gaze dispersion around the road centre. These trends were not exacerbated by simulated hearing loss, suggesting no effect of hearing loss on vehicle control or eye movement patterns during auditory task engagement. However, a small effect of simulated hearing loss on the performance of the most complex auditory task was observed during driving, suggesting that the use of sound-based in-vehicle systems may be problematic for hearing impaired individuals. Further research incorporating a wider variety of driving scenarios and auditory tasks is required in order to confirm the findings of this study.

Keywords: Hearing loss; sensory impairment; driving; cognitive workload; auditory distraction

1 Introduction

The effect of hearing loss on driving performance has been largely neglected in the road safety literature, perhaps because of the overwhelming reliance of driving on the visual modality (Sivak et al., 1996). Indeed, there is a wealth of research which has investigated the effect of visual sensory impairments on driving (see e.g. Owsley & McGwin, 2010 for a review), with a number of associated assessment techniques which can be used to identify at risk drivers. For example, the Useful Field of View test (Ball & Owsley, 1993) has shown a correspondence with measured driving performance and accident rates (Clay et al., 2005). However, only a handful of studies have looked at the effect of hearing impairment on driving performance, road traffic accidents, and driving cessation rates (Herbert et al., 2016). Much of the work in this area has been observational in nature, and the outcomes are heterogeneous, often because important variables such as annual mileage or driving experience are not controlled. Furthermore, these studies typically use self-reported measures of functional hearing loss, which may be problematic for drawing firm conclusions, as they can be subject to extraneous influences such as changes in cognitive and psychological factors (Salonen et al., 2011).

Whilst some hearing loss and road safety research shows an increased risk of road traffic accidents in hearing impaired individuals, it does little to explain why driving decrements may occur as a result of hearing impairment. The literature has largely been speculative, with some authors suggesting that hearing impaired individuals are unable to hear driving-relevant auditory information (Picard et al., 2008), and others suggesting that audible auditory information is more distracting for individuals with a hearing loss than those with normal hearing (Hickson et al., 2010).

There is little empirical evidence to support the suggestion that hearing impaired individuals are unable to hear driving-relevant sounds, although there has been some research investigating the distracting effect of audible information in hearing impaired drivers. For example, Hickson et al. (2010) asked older, normally hearing and hearing impaired individuals to drive a closed-road circuit whilst performing concurrent auditory and visual tasks. Their aim was to establish if sensory hearing loss increases the cognitive resource requirements of listening, thus partly removing capacity that could be used for other concurrent processes required for safe driving. The authors found that, compared to normally hearing participants, hearing impaired drivers were significantly less likely to recognise road signs, and showed an overall poorer driving performance (as indicated by a composite score of road sign recognition, gap perception, course completion time, and the number of road hazards hit) when required to complete an auditory task. Hickson et al. (2010) concluded that hearing impaired individuals should limit their engagement with in-vehicle devices, to ensure their driving safety is not affected. However, these conclusions should be treated with some caution as the authors' sample included only older hearing impaired individuals, aged between 62-88 years and the influence of age-related factors on performance cannot be excluded from these results.

An interesting, and unexpected, outcome of the Hickson et al. study (2010) was that hearing impaired individual's driving performance (indexed by their composite driving score) was also affected to a greater extent than their normally hearing counterparts by visual task engagement, although the authors offer little explanation for this finding. Similar results were observed in a study by Thorslund et al. (2013a), where hearing impaired individuals exhibited a more marked change in driving behaviour than a normally hearing sample, when completing a visually-presented in-vehicle task during driving. When hearing impaired drivers were asked to repeat back four visually-presented letters, their braking and evasive actions (such as passing a parked vehicle) were found to be affected, with slower speeds adopted by this group of drivers compared to the normally hearing sample. The authors suggested that cognitive resources were diverted from the driving task to the visual task for hearing impaired participants, because they require more explicit processing to perform lexical tasks due to the degradation of auditory representations in long-term memory (Andersson, 2002, Rönnberg et al., 2008). However, since the mean age of the groups recruited for the Thorslund et al. (2013a) study ranged between 60-62 years, it is also possible that their dual task performance was actually affected by an age-related decline of cognitive resources, rather than as a direct result of hearing loss. This argument is compatible with a common-cause hypothesis which suggests that sensory impairment is a marker of global cognitive decline (Li & Lindenberger, 2002), and is supported by studies which have reported a higher prevalence of cognitive decline in hearing impaired individuals (e.g. Baltes and Lindenberger, 1997). Overall these studies indicate an urgent need to explore the relationship between hearing loss and cognitive decline and the effect on driving performance, to allow a better understanding of the factors underpinning the driving abilities of hearing impaired people.

The aim of this study was to remove the effect of age-related cognitive decline on driving performed during concurrent auditory tasks, by presenting digitally processed auditory stimuli which simulated hearing loss to a sample of young, normally hearing drivers. The method of hearing loss simulation used has been shown to approximate the loudness, dynamic range and frequency selectivity of ‘real’ hearing impairment (Baer and Moore, 1994, Moore and Glasberg, 1997, Nejime and Moore, 1997). The rationale for using this method was partly due to difficulties in recruiting an adequate sample of young hearing impaired drivers for this study, but also to ensure that cognitive impairment was not a confounding factor. The research questions posed were:

1. Does auditory task performance whilst driving lead to any changes in driving performance?
2. Does the difficulty of the auditory task being performed alter these effects on driving performance?
3. When auditory stimuli used in these tasks are presented in a simulated hearing loss condition, are the effects on driving performance further changed?
4. Is there difference in the performance of the auditory task between the normal hearing and simulated hearing loss conditions whilst driving?

2 Method

2.1 Participants

36 young, normally-hearing participants (16 female; 20 male) were recruited from the University of Leeds Driving Simulator (UoLDS) participant database. The sample was aged between 20-40 years and had a mean age of 28.3 (S.D. = 5.7) years. Participants had 1-22 years of driving experience, with a mean of 9.5 years (S.D. = 6.3), and drove an average 6,900 (S.D. = 4,400)

miles per year. Participants were screened for normal hearing (absolute thresholds of ≤ 20 dB HL at frequencies of 0.25, 0.5, 1, 2, 4 and 8 kHz in both ears) using pure tone audiometry (British Society of Audiology, 2011) and were reimbursed £15 for taking part in the experiment. Ethical approval was granted for this study by the University of Leeds AREA Faculty Research Ethics Committee (reference: LTTRAN-048), and participants were required to give informed consent prior to participating.

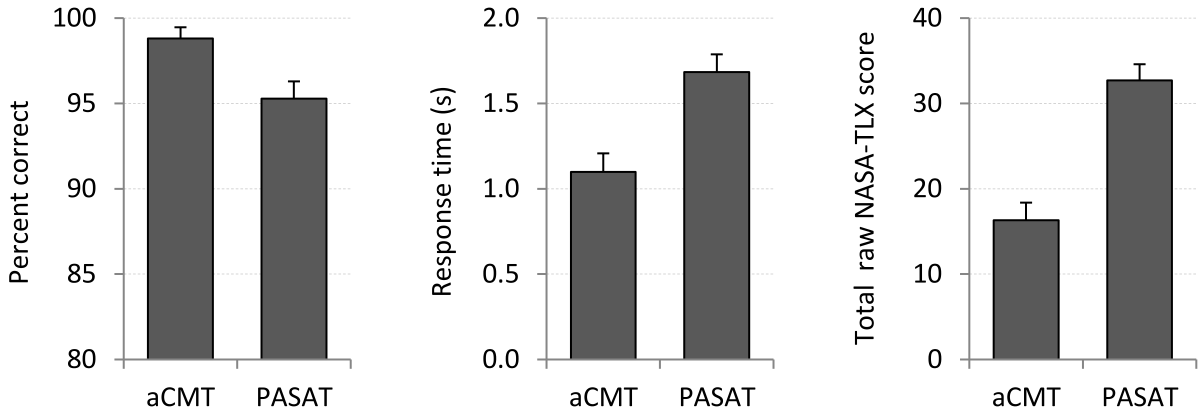
2.2 Materials

2.2.1 Driving simulator

This study used the UoLDS; a second-generation, moving-base, high fidelity facility (see Jamson et al., 2013 for a description). The simulated scene was based on a UK road system, consisting of a single carriageway rural road (speed limit 60 mph), which alternated between straight and gently curved sections, proceeding through a number of village settings (speed limit 40 mph). Whilst driving the course, participants were required to perform one of two auditory memory tasks at regular intervals, always during rural, straight sections of the road.

2.2.2 **Auditory memory tasks and simulated hearing loss**

To assess driving performance with a concurrent auditory task, two auditory memory tasks were chosen for this study; (1) the ‘Auditory Continuous Memory Task’ (aCMT), and (2) the ‘Paced Auditory Serial Addition Task’ (PASAT; Gronwall and Wrightson, 1974, Gronwall & Sampson, 1974). Previous studies on the effect of aCMT, which is an auditory manipulation of the visual continuous memory task (Veltman and Gaillard, 1998), have shown reduced lateral deviation during this task by normally hearing drivers when results were compared to baseline (Jamson and Merat, 2005). The PASAT has also been used in driving studies and shows a similar trend of reduced lateral deviation in normally hearing participants (Brookhuis et al., 1991). The main aim of selecting two auditory tasks was to assess the effect of task difficulty on performance. The selection of these tasks followed a short pilot study (unpublished), which confirmed that, in single task conditions, the aCMT was easier to perform than the PASAT (see Figure 1).



(a) accuracy (b) response time (c) perceived demand

Figure 1. Results from a pilot study in which 25 participants were asked to perform the aCMT and PASAT tasks under single-task conditions.

For the aCMT, participants were asked the number of times they heard a target number by keeping a cumulative count. The target digit was always the first number in a list of ten aurally presented digits, and participants were asked to count each occurrence of this digit. An example is shown below:

List:	2	6	3	6	2	2	1	2	2	4	
Answer:											5

For PASAT, participants heard a continuous string of numbers, and were asked to add together the two most recent. For example:

List:	2	6		3		6		2		2		1		2		2		4	
Answer:			8		9		9		8		4		3		3		4		6

Both tasks were system-paced, with the list of numbers occurring during a 30 second epoch at three designated periods during the straight sections of the rural road. Digits were played at a rate of one every 2 seconds, and if a digit was missed by participants they were instructed to simply ignore that number and continue listening to the list, counting targets or adding digits as they would have done without the error.

Each digit was presented at 80 dB(A) through the car speakers, providing a signal to road and engine noise ratio of +3 dB(A). The start and end of each digit list was signalled by a short (0.2 Second) 1000 Hz tone. Answers were given verbally at the end of aCMT, and throughout the PASAT. They were recorded by the experimenter, who was seated in the simulator control room.

Driving performance and eye movement behaviour were measured under three auditory conditions. The first with no sound present (baseline), and the second and third where the lists were digitally processed to represent normal hearing and a simulation of moderate sensorineural hearing loss respectively. A moderate level of hearing loss was chosen for this study as previous work has suggested that this is the level at which hearing loss begins to present problems for driving (Hickson et al., 2010). The magnitude and configuration of the moderate hearing loss used for the simulation is representative of mean thresholds taken from a large sample (n = 3,753) of 48-92 year olds, published elsewhere (Cruickshanks, 1998).

The simulation of hearing loss was implemented by applying a previously published digital signal processing technique (Baer & Moore, 1993, Moore & Glasberg, 1993) to emulate the most troublesome aspects of sensorineural hearing loss for speech understanding: threshold elevation, loudness recruitment, and reduced frequency selectivity (Moore, 2007). These stimuli have been shown to approximate ‘real’ hearing impairment accurately (Baer & Moore, 1994, Moore & Glasberg, 1997). Although the auditory tasks were presented at 80 dB(A), their level and frequency content were attenuated by factors typical of a moderate sensorineural hearing loss (SNHL). This was confirmed in a pilot study, where the simulation was used to process standard speech test materials presented to a sample of 12 (6 female; 6 male) normally hearing 20-28 year olds. Results closely reflected values expected from individuals with a moderate SNHL. Therefore, the signal to road and engine noise ratio used in this study would have been reduced to levels typically found when listening whilst driving for those with a moderate SNHL.

2.3 Design and Procedure

2.3.1 Practice Session

Before driving the experimental road, participants practiced the two auditory memory tasks in isolation, under both normal hearing and simulated hearing loss conditions, until they achieved an accuracy of 75% or more. Following single task practice, participants then completed a practice drive, in the presence of the experimenter. Following a short section of roadway with no secondary tasks, whilst driving, participants practiced the PASAT and aCMT tasks, presented in both the normal hearing and simulated hearing loss conditions. The practice session lasted approximately 25 minutes.

2.3.2 Experimental Drive

Upon successful completion of the practice session, participants completed two experimental drives, which lasted around 30 minutes each, separated by a short break to reduce fatigue. To avoid confusion, only one auditory task was completed per experimental drive, which was counterbalanced across participants. In each drive, participants followed a lead vehicle which kept a consistent speed (governed by the speed limit imposed). A constant opposing flow of traffic was present in order to reduce the likelihood of overtaking the lead car. Participants were asked to pay equal attention to both tasks, as much as possible. Each auditory task lasted 30 seconds, and three blocks of task (the simulated hearing loss and normal hearing conditions, and a corresponding baseline with no auditory task) were presented per drive. The order of these tasks was counterbalanced across participants.

2.3.4 Dependent Variables

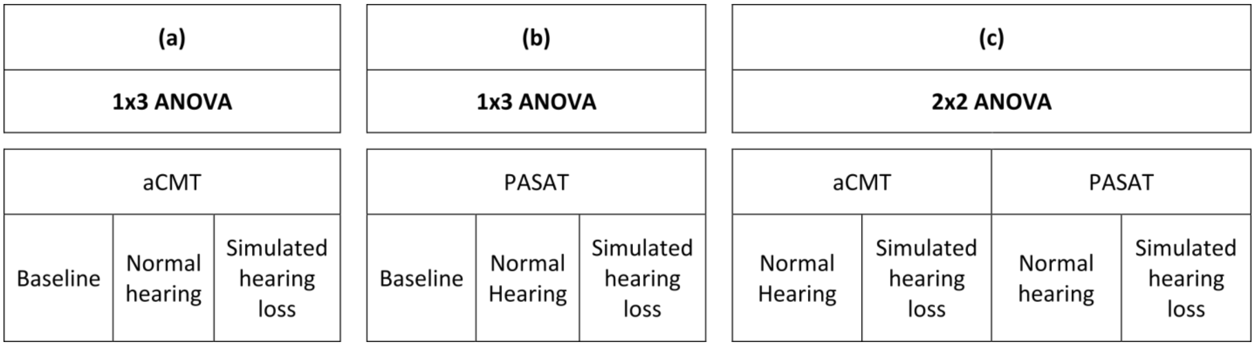
Driving performance was assessed in each auditory condition by measuring selected lateral and longitudinal measures of vehicle control (see Knappe et al., 2007); speed, headway, standard deviation of lateral position (SDLP), minimum time to line crossing (TTLC) and high frequency component of steering wheel angle (HFC).

Percent Road Centre (PRC), defined as a 6° circle around the mode point of fixation for the entire drive (Jamson et al., 2013), was calculated using the SeeingMachines faceLAB (v5). Gaze dispersion was also calculated as the standard deviation of gaze vector points, calculated by combining raw pitch and yaw gaze points (Wang et al., 2104). Previous studies have shown reduced gaze dispersion around the centre of the road and a reduction in peripheral glances during driving when participants are engaged in a concurrent auditory-vocal cognitive task (Victor, 2005; Kountouriotis & Merat, 2016).

Auditory task accuracy (the number of correct answers as a proportion of the number of stimuli) and adherence (the number of responses given as a proportion of the number of stimuli) were measured for both PASAT and aCMT.

2.3.5 Data Analysis

As outlined in Figure 2, three analyses of variance were performed on each individual driving performance and eye movement dependent variable described in section 2.3.4. First, to investigate whether the performance of an auditory task affected driving performance or eye movements, two separate one-way ANOVAs with 3 conditions (baseline, normal hearing, simulated hearing loss) were performed for aCMT and PASAT data respectively (see Figures 2a and 2b; N.B. baseline refers to driving without a secondary task present). Note that because aCMT and PASAT were performed in different drives, a baseline measure was taken in each of these drives. Second, to test for differences between the change in dependent variables from baseline as a result of the type of auditory memory task undertaken, a 2 x 2 (aCMT, PASAT x normal hearing, simulated hearing loss) repeated measures ANOVA was performed (see Figure 2c). The 2 x 2 ANOVAs were performed on individual values calculated as the difference between the simulated hearing loss or normal hearing condition and the baseline condition of the corresponding drive.



(a)		
1x3 ANOVA		
aCMT		
Baseline	Normal hearing	Simulated hearing loss

(b)		
1x3 ANOVA		
PASAT		
Baseline	Normal Hearing	Simulated hearing loss

(c)			
2x2 ANOVA			
aCMT		PASAT	
Normal Hearing	Simulated hearing loss	Normal hearing	Simulated hearing loss

Figure 2. The different ANOVA designs used in the analysis of this experiment (N.B. baseline refers to driving without a secondary task present).

3 Results

3.1 Driving Performance

The one-way repeated measures ANOVAs applied to each of mean, minimum, maximum and standard deviation of speed and headway indicated that no measures of longitudinal vehicle control were significantly altered as a result of different experimental conditions. The 2 x 2 (aCMT, PASAT x normal hearing, simulated hearing loss) ANOVAs on these variables also revealed no main effects of auditory task or listening condition, or significant interactions.

A one-way repeated measures ANOVA (baseline, normal hearing, simulated hearing loss) of SDLP recorded during the performance of aCMT showed a main effect of listening condition (F(2,70) = 3.38, p = .040). Subsequent post-hoc pairwise comparisons showed no statistically significant differences between the conditions, although the difference between the baseline and simulated hearing loss conditions did tend towards significance (p = .052). However, Figure 3a clearly shows that SDLP was lower when drivers performed the aCMT in the simulated hearing loss or normal hearing condition, compared to the baseline condition.

A one-way repeated measures ANOVA (baseline, normal hearing, simulated hearing loss) of SDLP recorded during the performance of PASAT also showed a main effect of listening condition (F(2,70) = 6.70, p = .002). Post-hoc analysis confirmed that lane position was less variable when PASAT was completed under normal hearing (p = .010) or simulated hearing loss (p = .012) conditions, compared to the baseline condition (see Figure 3b).

A 2 x 2 (aCMT, PASAT x normal hearing, simulated hearing loss) repeated measures ANOVA of the change in SDLP as a result of auditory task engagement did not reveal any main effects of task (F(1,35) = 0.01, p = .90) or listening condition (F(1,35) = 0.24, p = .62), or an interaction between the two F(1,35) = 0.05, p = .82). This suggested no difference between SDLP during aCMT or PASAT, or the normal hearing or simulated hearing loss conditions (see Figure 3c).

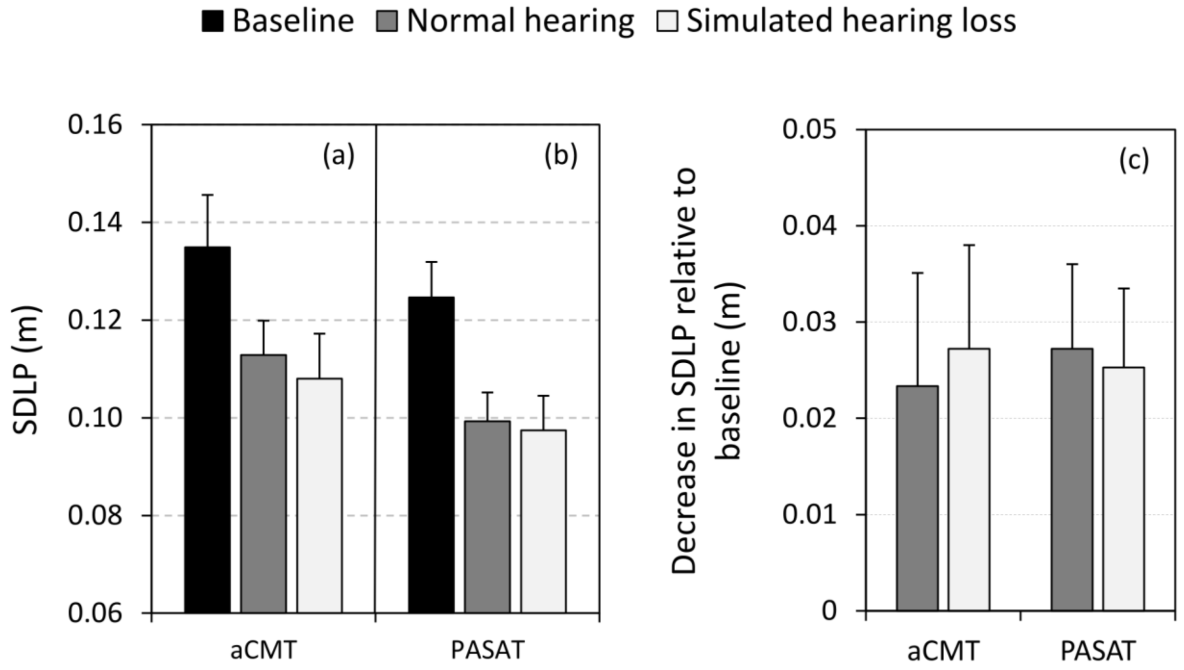


Figure 3. SDLP values (± standard error) for the different ANOVAs conducted in this study.

Regarding the effect of tasks on other lateral vehicle control measures, no significant differences in TTLC were found across the different experimental conditions, nor were any found for HFC.

3.2 Eye tracking data

A one way repeated measures ANOVA (baseline, normal hearing, simulated hearing loss) of PRC data during the performance of aCMT showed a main effect of listening condition ($F(2,66) = 11.08$, $p < .001$). This was because PRC was higher during the performance of aCMT in the normal hearing ($p = .016$), and simulated hearing loss conditions, compared to the baseline condition ($p < .001$). However, the normal hearing and simulated hearing loss conditions did not differ from each other (see Figure 4a).

A one way repeated measures ANOVA (baseline, normal hearing, simulated hearing loss) revealed no main effect of listening condition for PRC data recorded during the performance of PASAT (F(2,66) = 0.67, p = .513; see Figure 4b).

A separate 2 x 2 (aCMT, PASAT x normal hearing, simulated hearing loss) repeated measures ANOVA on the change in PRC from baseline showed a main effect of auditory task (F(1,33) = 6.88, p = .013), indicating that the increase in PRC from baseline was significantly higher when performing aCMT compared to PASAT. No main effect of listening condition was found (F(1,33) = 0.85, p = .92), nor was an interaction between auditory task and listening condition present (F(1,33) = 0.46, p = .50; see Figure 4c).

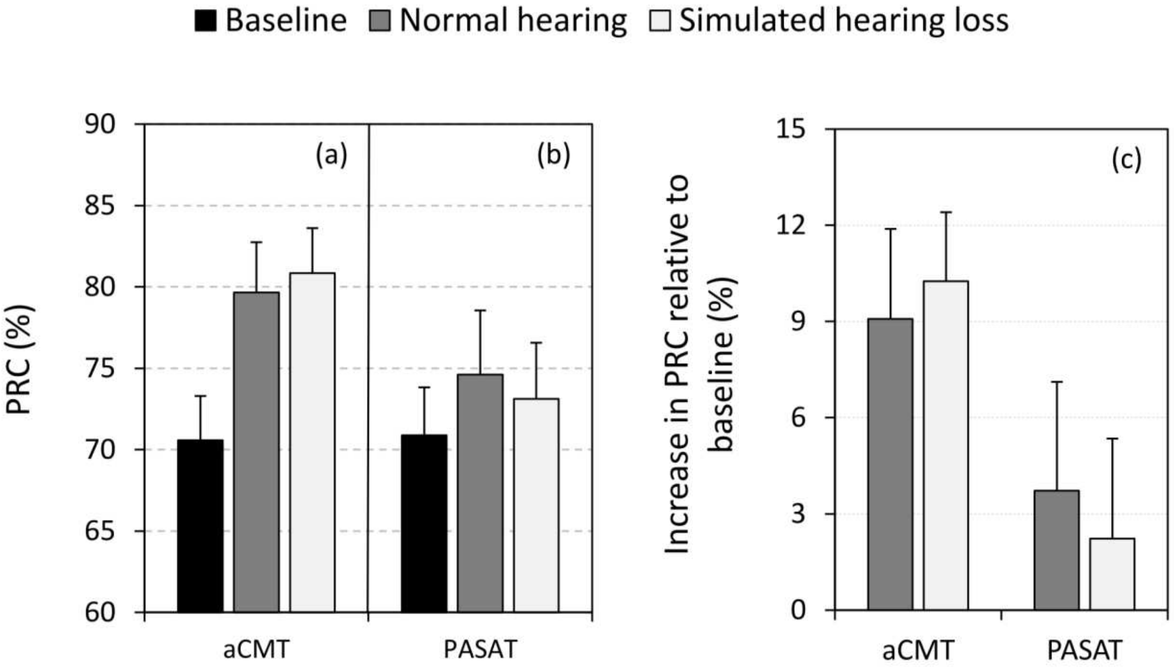


Figure 4. PRC values (± standard error) for the different ANOVAs conducted in this study.

A one way repeated measures ANOVA (baseline, normal hearing, simulated hearing loss) of gaze dispersion data recorded during the performance of aCMT showed a main effect of listening condition (F(2,66) = 17.66, p = .001). Gaze was less dispersed during the performance of an auditory task, whether in the normal hearing (p < .001) or simulated hearing loss (p < .001) condition, compared the baseline condition. The normal hearing and simulated hearing loss conditions did not differ significantly from each other (p = 1.00; see Figure 5a).

A one way repeated measures ANOVA (baseline, normal hearing, simulated hearing loss) of gaze dispersion data recorded during the performance of PASAT also showed a main effect of listening condition (F(2,66) = 9.97, p < .001). This arose because gaze was less dispersed in the normal hearing (p = .017) and simulated hearing loss (p = .001) condition, in comparison to the baseline condition. Again, the normal hearing and simulated hearing loss conditions did not significantly differ from each other (p = 1.00; see Figure 5b).

A 2 x 2 (aCMT, PASAT x normal hearing, simulated hearing loss) repeated measures ANOVA on the change in gaze dispersion from baseline revealed no main effect of auditory task (F(1,33) = 0.56, p = .46), listening condition (F(1,33) = 2.41, p = .13), or an interaction between the two (F(1,33) = 0.12, p = .74; see Figure 5c).

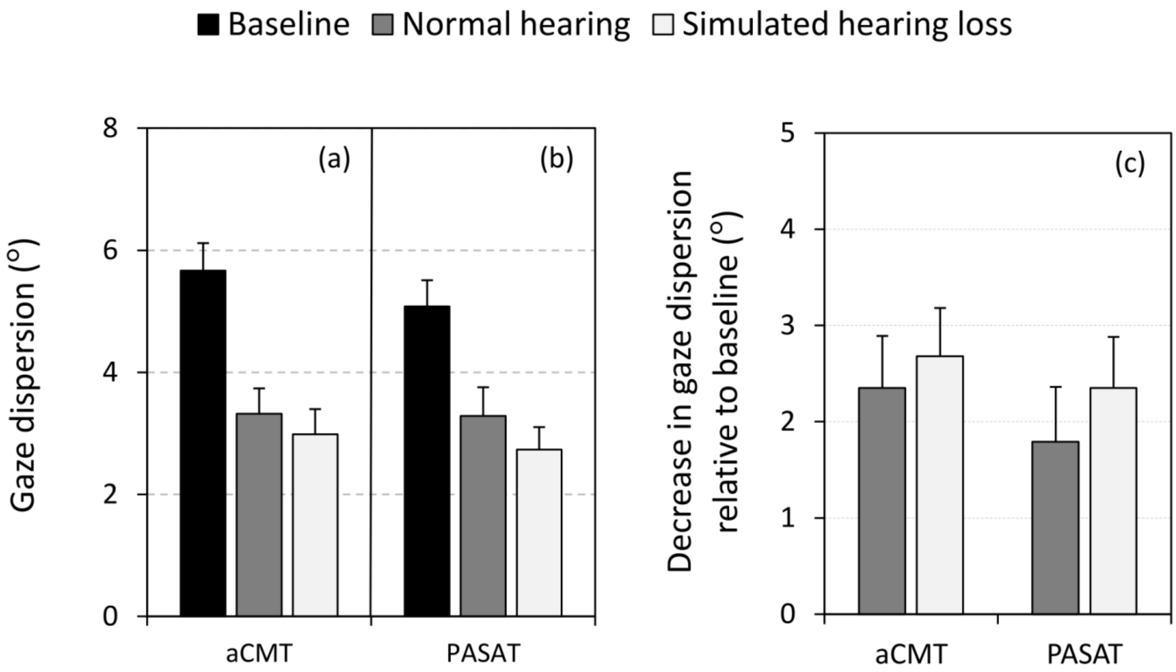


Figure 5. Gaze dispersion values (± standard error) for the different ANOVAs conducted in this study.

3.3 Auditory task performance

A Wilcoxon Signed Rank test revealed no significant difference between the normal hearing and simulated hearing loss conditions for the accuracy of, or adherence to aCMT. However, PASAT performance was significantly more accurate when it was presented in the normal hearing condition (M = 88.2% correct) compared to the simulated hearing loss condition (M = 78.5% correct; Z = -2.86, p = .004). No difference between the two listening conditions in terms of the number of answers given by participants was observed, with a mean of 94.8% answers given in the normal condition, and 91.2% in the simulated hearing loss condition.

4 Discussion

The aim of this study was to explore the effect of two cognitively engaging auditory tasks on driving performance and eye movement behaviour, and to investigate whether this performance was likely to be affected by simulated hearing loss. The first research question posed was whether auditory task performance whilst driving led to more stable lateral vehicle control and a reduction in gaze dispersion. Results showed that, in both the normally hearing and simulated hearing loss conditions, performing either aCMT or PASAT led to an increased stability in lateral vehicle control, as illustrated by SDLP, consistent with previous studies in this context (e.g. Brookhuis et al., 1991, Engström et al., 2005a, Jamson & Merat, 2005). Participants' gaze dispersion was also reduced by performance of the auditory tasks, regardless of listening condition. This is in line with previous studies, which have proposed a link between gaze concentration during engagement in an auditory task and improved lateral vehicle control. They suggest that this is caused by a prioritisation of lane-keeping which treats gaze concentration as a compensation mechanism (Victor et al., 2005). A similar view is proposed by the Active Gaze model of steering, which suggests that drivers' eye-movements are inexorably linked to steering patterns (Wilkie & Wann, 2003, Wilkie et al., 2008).

The second research question was whether increasing the difficulty of the auditory task being performed altered these effects on driving performance. In line with previous studies, we expected reduced deviation in lane position (Jamson & Merat, 2005) and an increase in gaze concentration (Reimer et al., 2010) with increasing auditory task difficulty. However, we found no evidence that the decrease in SDLP or gaze dispersion was significantly different between the two auditory tasks used. In fact, in terms of eye movement behaviour, there was a significant increase in PRC as a result of the easier aCMT task, but not as a result of the more difficult

PASAT task. It is not clear why the effect of the two auditory tasks was broadly comparable, given that we confirmed the PASAT was more challenging in a pilot study testing the two auditory tasks in single task conditions. Prior research has manipulated the difficulty of auditory tasks by changing the amount of information which must be stored in memory (e.g. Jamson & Merat, 2005). This study did not alter the difficulty of the auditory task in this manner, instead changing the cognitive processing required to complete the task. It may be beneficial for future work to establish the effect of different types of auditory task on measures of driving performance and eye movement behaviour.

A third research question was whether the performance of the auditory tasks during a simulated hearing loss condition affected driving performance measures to a greater extent than in the normal hearing condition. Results revealed no difference in lateral control measures, or any changes in eye movement patterns when the aCMT and PASAT were completed with simulated hearing loss, compared to normal hearing. One possible explanation for this finding is that participants withdrew from the more difficult auditory task (PASAT) in the simulated hearing loss condition. However, although there was a significant reduction in the accuracy of PASAT when it was performed in the simulated hearing loss condition, the number of answers given to both auditory tasks remained constant between listening conditions. Furthermore, the effect of concurrent auditory tasks on driving performance and eye movement behaviour was comparable between the normal hearing and simulated hearing loss conditions, suggesting that equal cognitive effort had been exerted in each condition.

Since the hearing loss simulation used in this study was an accurate representation of sensory loss, the lack of an effect from this manipulation on driving performance over and above that of the normal hearing condition suggests that the particular aspects of hearing loss emulated were not likely to contribute to impairments in driving performance during distraction from an auditory task. These results are in conflict with studies using participants with real (rather than simulated) hearing loss, which, for instance, suggest a reduction in the useful field of view of hearing impaired drivers during auditory task performance (Hickson et al., 2010). Recent work aiming to confirm this finding has also suggested that hearing impaired participants show a greater primary task decrement than those with normal hearing as a result of concurrent auditory task engagement (Herbert et al., 2016). The effect of such impaired performance by the hearing impaired has been linked to an increased risk of road traffic accidents for this demographic (Barreto et al., 1997, Ivers et al., 1999, Picard et al., 2008). A key difference between these studies and the current study, however, is the use of a simulated hearing loss to emulate auditory impairment. It is possible, therefore, that aspects of hearing loss not emulated by the simulated hearing loss (e.g. reduced temporal processing, central auditory processing capabilities) may have contributed to the decrements observed in past research. However, this is unlikely, as the aspects of sensorineural hearing loss deemed most problematic for speech understanding were covered by this simulation (Moore, 2007), and pilot testing approximated results that would be expected from participants with a 'real' hearing impairment.

Another possibility is that factors which often co-exist with hearing loss, such as cognitive decline (Salthouse, 2000), have a role to play in the driving performance of hearing impaired individuals. In this experiment, a young, normally hearing sample was recruited, in order to remove the effect of age-related declines in cognitive ability on performance. Whilst this approach differentiated the effect of any auditory sensitivity loss from cognitive factors, it does not accurately reflect the demographic of hearing impaired individuals, since hearing loss is a largely age-related condition (Davis, 1995), and a large proportion of individuals with this sensory impairment are also likely to have experienced a decline in cognitive resources through healthy ageing (Humes et al., 2012). Furthermore, previous studies have also observed a higher prevalence of cognitive decline in hearing impaired populations (e.g. Baltes and Lindenberger, 1997). It is therefore possible that studies using 'real' hearing impaired individuals are partly confounded by disregarding the influence of impaired cognitive resources on performance. This absence of a difference in performance between simulated hearing loss and normal hearing highlights the possibility that a synergistic effect of hearing loss and co-existing cognitive factors may be responsible for driving decrements in the hearing impaired demographic. This relationship may be better understood by comparing samples of older and young hearing impaired individuals.

The final research question was whether auditory task performance during driving differed between the normal hearing and simulated hearing loss conditions. Participants’ performance in the most complex auditory task (PASAT) was affected by simulated hearing loss. We interpreted this finding as evidence that the simulated hearing loss functioned as expected, reducing auditory task performance as a result of an increased listening effort. When the listening task became more difficult, as a result of simulated hearing loss, the demands imposed were sufficient to cause a disruption on performance of PASAT. This problem may be exacerbated by the concurrent driving task, although it cannot be inferred from this study. Regardless, this suggests a need to be aware that hearing impaired individuals may struggle to use complex auditory-based in-vehicle devices. Current research which focuses on creating a more accessible version of these systems for hearing impaired individuals (e.g. Thorslund et al. 2013b) is therefore considered valuable.

Finally, it should be considered that this study has investigated the effect of hearing loss on driving in a single driving scenario, using two auditory memory tasks. The employment of either more complex driving scenarios (e.g. traversing intersections or lane changing tasks) or more complex auditory processing tasks (e.g. sentence or prose processing) may be useful to further understand the effect of hearing impairment on driving performance.

5 Conclusions

Engagement with an auditory task resulted in more stable lateral vehicle control and a reduction in gaze dispersion around the road centre. The difficulty of the auditory task being undertaken interacted with these trends, but the presence of a simulated hearing loss had no extraneous effect. Despite this, there was some evidence that auditory task performance whilst driving suffered as a result of simulated hearing loss, suggesting that the use of auditory-based in-vehicle systems may be problematic for hearing impaired individuals.

These outcomes suggest that a facet of hearing impairment not captured by the simulation technique used may be responsible for some previously observed decrements in hearing impaired individuals' driving performance. These factors may be psychoacoustic phenomena associated with sensory hearing loss, or co-existing cognitive factors which were not present in the study sample. Further work is required to confirm the findings of this study across a range of driving scenarios and auditory tasks, and in order to establish the extent to which cognitive factors play a part in the driving performance alterations of hearing impaired individuals. Work measuring other dependent variables which might be affected in hearing impaired drivers, such as the ability to react to visual information in the driving environment, would also be of value.

6 Acknowledgements

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