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The Effect of Auditory Distraction on the Useful Field of View in Hearing Impaired Individuals and its Implications for Driving

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Abstract: This study assessed whether the increased demand of listening in hearing impaired individuals exacerbates the detrimental impact of auditory distraction on a visual task (Useful Field of View test), relative to normally hearing listeners. Auditory distraction negatively affects this visual task, which is linked with various driving performance outcomes. Mildly-severely hearing impaired and normally hearing participants performed Useful Field of View testing with and without a simultaneous listening task. They also undertook a cognitive test battery. For all participants, performing the visual and auditory tasks together reduced performance on each respective test. For a number of subtests, hearing impaired participants showed poorer visual task performance, though not to a statistically significant extent. Hearing impaired participants were significantly poorer at a reading span task than normally hearing participants, and tended to score lower on the most visually complex subtest of the visual task in the absence of auditory task engagement. Useful Field of View performance is negatively affected by auditory distraction, and hearing loss may present further problems, given the reductions in visual and cognitive task performance suggested in this study. Suggestions are made for future work to extend this study, given the practical importance of the findings.

Keywords: Useful field of view (UFOV), distraction, hearing loss, listening effort, attention, driving

1. Introduction

The effect of hearing impairment on driving is an area of research which has received little attention to date, although a small number of studies have begun to suggest that there may be a relationship between the two. A large proportion of this work has not measured driving performance directly, instead focussing on road traffic accident or driving cessation rates for hearing impaired individuals compared to those with normal hearing. The outcomes of these studies are heterogeneous (see Table 1), with some exhibiting an increased risk of negative driving outcomes as a result of hearing loss (Barreto et al., 1997, Ivers et al., 1999, Gilhotra et al., 2001, Picard et al., 2008), but others showing no such association (McCloskey et al., 1994, Sims et al., 2000, Unsworth et al., 2007, Green et al., 2013). Accordingly, there has been no consensus reached over whether hearing loss has an impact on driving safety.

Despite the possibility that hearing loss might affect driving safety, there is little suggestion as to why, exactly, hearing loss affects driving performance. Some authors have suggested that hearing impaired individuals are simply unable to hear salient auditory information in the driving environment (Picard et al., 2008). However, another recent explanation is that hearing impaired individuals may be more susceptible to the effects of auditory distraction whilst driving in comparison to normally hearing individuals (Hickson et al. 2010). It has been shown that the extra cognitive effort required in understanding a distorted auditory signal impacts on operations at later stages of information processing (Rabbitt 1968), and when the source of this auditory distortion is hearing impairment, a negative impact on memory span tasks has been found (Rabbitt 1991, McCoy et al. 2005). This suggests that hearing impairment may affect the performance of tasks relying on audition, or those performed concurrently with such tasks (e.g. driving whilst conversing with a passenger).

To explore this theory, Hickson et al. (2010) asked normally hearing and hearing impaired individuals to drive a closed-road circuit, undertaking various tasks set up along the course (such as reporting the presence and content of road signs). Whilst driving, participants were asked to concurrently perform a listening task (adding together two aurally presented numbers). The authors hypothesised that hearing impaired individuals would be more affected by this, because of an increase in mental effort associated with the auditory task (Wingfield et al., 2005). They noted that road sign recognition whilst driving was more affected by auditory distraction in their hearing impaired subjects than their normally hearing group. Although it cannot be directly inferred from the results of Hickson et al. (2010), this finding corresponds with research showing an effect of auditory distraction on the 'useful field of view': "the visual field area over which information can be acquired in a brief glance without eye or head movements" (Edwards et al. 2006 p.275). This research suggests that the useful field of view is reduced when a cognitively engaging auditory task is being simultaneously undertaken (Wood et al. 2006), and that this is likely to be more marked the more challenging the auditory task becomes (Pomplun et al. 2001). Because hearing impairment is thought to increase the cognitive demands of listening (Shinn-Cunningham and Best 2008), the current study hypothesised that hearing impaired individuals should experience an even greater reduction in their useful field of view than normally hearing individuals whilst engaged in an auditory task. Confirmation of this hypothesis would suggest an explanation for the finding of Hickson et al. (2010).

The useful field of view can be assessed using a computer-based test (UFOV®), which measures skills thought to be used during driving (Ball and Owsley 1993). Thus, the assessment has been employed extensively in studies investigating the driving ability of older adults. Evidence has shown that UFOV performance predicts driving competence (Owsley et al. 1998), vehicle crashes (Ball et al. 1993, Owsley et al. 1998), and driver safety (Clay et al. 2005). This evidence, and the fact that UFOV can be administered without specialist training in a short amount of time (Classen et al. 2009), has led to suggestions that UFOV may be suitable as a tool to quickly and reliably identify at-risk drivers (Bédard et al. 2008). This suggested predictive nature of UFOV is likely due to its hypothesised reliance on both visual sensory abilities and higher order attentional skills (Owsley, 1994). Indeed, previous work suggests that the functional visual field is reduced by increases in cognitive load (Rantanen & Goldberg, 1999; Williams, 1982; Williams & Lefton, 1981).

Data presented by Wood et al. (2006) agrees, showing that the concurrent performance of an auditory task resulted in more perceptual errors being made in the visual field. They argued that their finding had implications for safe driving. Other studies investigating the effect of auditory task engagement on the functional visual field have produced similar results, which have then been extrapolated to the driving domain (Atchley & Dressel, 2004). These two studies suggest that auditory distraction will impact on scores obtained on UFOV, and, by association, lower driving safety and competence under these conditions. The effect of auditory distraction on UFOV is likely to be exacerbated in hearing impaired individuals, as hearing loss places an extra cognitive demand on listening (Shinn-Cunningham and Best 2008), essentially increasing the difficulty of the auditory task. However, this is yet to be empirically investigated; Atchley & Dressel (2004) and Wood et al. (2006) only studied individuals with normal hearing.

The proposition that hearing impairment may exacerbate the effects of in-vehicle auditory distraction is pertinent given the increasing complexity of the in-car environment (Hickson et al. 2010). Furthermore, hearing impairment is a prevalent condition, estimated to affect approximately 10% of the population in Western countries (Arlinger, 2003). Therefore, it is important to assess the effect of distraction on tasks relevant to driving in hearing impaired individuals, so that any detrimental effects can be identified and interventions can be devised, should there be a need for them. The aim of this study was to extend the findings of Wood et al. (2006) by establishing whether hearing loss exacerbates the effect that auditory distraction has on the performance of UFOV, as they found for normally hearing subjects.

2. Material and methods

2.1 Participants

16 hearing impaired participants were recruited to this study from the Audiology department at Linköping University Hospital. 16 individuals reporting normal hearing (matched in terms of age and gender to the hearing impaired cohort) were recruited from the local community. All participants were in good general health, and free from eye and ear disease. They held a current, valid driver's licence and wore any optical correction normally worn for driving. Pure tone audiometry was conducted on each participant in accordance with the British Society of Audiology guidelines (2011) in order to confirm the presence hearing loss. Participants were split in to two groups: a normal hearing group who all had hearing thresholds better than or equal to 20dB HL across octave frequencies between 250 and 4 Khz, and a hearing impaired group who did not fulfil this criterion. Hearing thresholds for both groups are given in Figure 1 and demographic information is given in Table 2. One of the hearing impaired participants had an average hearing threshold of 74dB HL, and so was

classified as having a ‘severe’ level of hearing loss (British Society of Audiology, 2011). Since presentation levels were specified in dB sensation level, this participant was able to hear all auditory stimuli during the experiment. Three of the participants in the hearing loss group had a congenital hearing loss, the other fourteen had an acquired hearing impairment. Fourteen of the group owned bilateral hearing aids, two owned unilateral hearing aids, only one participant with a hearing loss did not own a hearing aid. Of the sixteen participants who owned hearing aids, eleven wore them all of the time, three wore them occasionally, and two never wore them. Nobody reported differing behaviour with regard to hearing aid use whilst driving.

2.2 Stimuli

2.2.1 Cognitive Testing

Given UFOVs reliance on higher-order processing abilities (Edwards et al. 2006), a cognitive test battery was employed. ‘KIPS’, a developed, abbreviated version of the cognitive test battery `TIPS’ (Lyxell et al. 1998), was used in order to assess working memory capacity, lexical access speed and phonological skills (Borg et al. 2008). The test was administered on a personal computer, requiring responses using the mouse and/or keyboard. The test battery consisted of four sections, and lasted approximately 17 minutes in total:

1. **Physical matching**: participants had to decide whether two letters appearing on the monitor looked the same or different.
2. **Lexical text**: participants had to decide whether words that appeared on the screen one at a time were real, or invented.
3. **Rhyme**: participants had to decide whether two words displayed simultaneously on the monitor rhymed with each other or not.

4. **Reading span**: sets of two 3–5 word sentences were displayed on the monitor one word at a time. Participants had to decide whether or not each sentence made sense or was nonsense. Once this choice had been made, the participant was asked to recall either the first or the last word in both preceding sentences.

2.2.2 Visual Task

UFOV test software (v6.1.1, Visual Awareness Research Group Inc.) was used to assess the useful field of view of participants. This software consists of three screening subtests, each of which was used in this study. Each subtest consisted of a number of trials beginning with an empty screen with a central outline of a white square subtending approximately 3.5^{o} at the eye. Visual 'targets' were then presented followed by a noise masking screen, and then finally the response screen(s) (see Figure 2). The central task was to specify which of two pictures (always a car or a truck) flashed up in the centre square, and the peripheral task was to indicate at which of eight possible locations a picture (always of a car), at a visual eccentricity of approximately 29^{o}, was presented. Each subtest varied slightly in terms of the targets presented:

1. **Subtest 1** – central task: perform the central task alone (no peripheral target is presented).
2. **Subtest 2** – central and peripheral task: perform the central and the peripheral task simultaneously.
3. **Subtest 3** – central and peripheral task, with visual distracters: the same stimuli as subtest 2, however a distracter array of 47 triangles was presented simultaneously with the stimuli (see Figure 2).

Each subtest consisted of a variable number of trials (range = 13–51) as the number of presentations was controlled by participant consistency. The epoch of stimulus presentation also varied between trials (range 17–500ms), again depending on the accuracy of responses given by respective participants (see section 2.4.2 for details). Participants were automatically presented with a response screen following each stimulus (see Figure 2). Responses were made with a computer mouse by navigating to their chosen answer shown on the screen and left-clicking. This method of response has been shown in past research to have a high test-retest repeatability of 0.884 (Edwards et al. 2005).

2.2.3 Auditory Task

The auditory distraction task used in this study was a dichotic listening test developed by Hällgren et al. (1998), which consisted of two five-word, low-redundancy, sentences being played to opposing ears simultaneously. This task was chosen because such a dichotic listening task that requires a response has been shown to affect the span of visual search (Wood et al. 2006). Furthermore, the test provides a level of face validity for driving under certain circumstances (e.g. conversing with a passenger whilst listening to a radio program), and its temporal properties make it ideal for coinciding auditory stimuli with UFOV stimuli. The auditory stimuli were presented using Telephonics TDH-39P headphones. Subjects were required to listen to the stimuli in full before repeating back as much of both sentences as they had heard. As these stimuli were being presented through headphones, participants were not permitted to wear hearing aids during the experiment, even if they did so under normal driving conditions. For this reason auditory stimuli were presented at a level of 50 dB HL sensation level, so that sounds were played at an audible level for all participants, regardless of hearing loss. To a certain extent, this approach emulates the primary goal of hearing aids (Hogan and Turner 1998). In cases where the extent of hearing loss made this sensation level uncomfortably loud, stimuli were adjusted to an intensity deemed comfortable by participants.

2.3 Procedure

Audiological testing and the cognitive test battery were both undertaken prior to starting UFOV testing. Participants were then seated 60 cm away from the 17 inch UFOV computer monitor. Participants were instructed how to perform UFOV with the aid of sample stimuli contained within the software and were then given a practice as per the test instructions. Practice continued until 75% of trials were correctly performed, or until 16 trials had been presented. Participants were then given the opportunity to practice UFOV simultaneously with the auditory task, using the same stimuli as in the experimental session. Again practice was stopped once 75% of trials had been successfully completed, or 16 trials had been presented. Following the training and practice session, participants went on to complete the three UFOV subtests described above both with and without the auditory task presented simultaneously. This resulted in six experimental conditions, which were partially counterbalanced using the balanced Latin Square method. A baseline measure of auditory task performance on its own was also taken, whereby participants responded to ten auditory stimuli. Half of each experimental group undertook this baseline measure before performing the six experimental conditions, the other half performed it at the end of the experimental session.

2.4 Measures

2.4.1 Cognitive Testing

The KIPS software measured participant performance (percentage correct) on each of the cognitive battery subtests (as described in section 2.2.1). Each individual section of the test battery could be analysed independently.

2.4.2 Visual Task

Visual task scores ranged between 17 – 500 ms. Scores were given as the stimulus epoch required to achieve 75% successful performance of UFOV trials. Therefore a lower score meant better subtest performance. The UFOV software derived visual task scores by varying the stimulus presentation duration depending upon correct/incorrect responses, presenting stimuli using a double staircase method. Subtests ended automatically once the software had a stable estimate of the required stimulus epoch.

2.4.3 Auditory Task

Auditory task responses were also recorded when present in the experimental condition, and during the baseline measure of auditory task performance. A percentage correct score was calculated for each participant during each subtest by counting the number of correct words repeated following each stimulus presentation. As there were five words in each sentence, the maximum score for each stimulus was ten. A similar approach to marking this auditory task has been taken in past research, which asked participants to report the sentence from one ear only (Hällgren et al. 2001). However, the current study asked participants to recall as much of both sentences as possible. This approach was taken in order to avoid the possibility of cueing participants towards a certain side of their visual field as a result of directed auditory stimuli, as has been suggested by past research (Ho et al. 2006). Accordingly, sentences were analysed such that if a participant only gave one-sentence as a response, marks were not awarded for words from both stimuli sentences. Instead marks were only given from the sentence that scored highest. For example:

Stimuli: “Elsa borrowed three dark gloves” & “Bosse owned six beautiful rings”

Response 1: “Bosse owned six beautiful rings” & *no response*. **Score given = 5/10**

Response 2: “Bosse borrowed three beautiful rings” & *no response*. **Score given = 3/10**

Response 1 scores 5/10, as the participant has repeated only one sentence in its entirety, but the sentence given is correct. Response 2 only scores 3/10, as the participant has only repeated one sentence, and the answer given is a mixture of the two stimuli sentences. The 3 marks given are, therefore, for the participant saying ‘Bosse’, ‘beautiful’ and ‘rings’, all three of which are present in the second stimuli sentence. Marks are awarded from this particular sentence as the responses recorded to the other stimulus sentence would have resulted in a lower score of 2/10. This approach was taken in order to reflect the difficulty of the listening task. It was not considered feasible to give the same mark to somebody repeating a mixture of the two stimuli sentences, and another person successfully ignoring an interfering stimulus, listening to one of the sentences, and repeating it in its entirety.

3. Results

The mean scores obtained by both experimental groups on the KIPS cognitive test battery are shown in Figure 3. Performance on the majority of these tests was accurate, with the mean scores obtained being around 90% or above. However, ‘reading span’ scores were generally lower than the other 3 sections for participants of both groups. In fact, there was a significant difference in scores on the reading span section of the KIPS test battery between the hearing impaired group (M = 50.94, SEM = 2.57) and the normally hearing group (M = 61.07, SEM

= 2.53); $t(30) = -2.793$, $p = .009$, $r = .45$. The hearing impaired group also scored lower on average for the 'rhyme' section of the KIPS test than did the normally hearing group, though this difference was not significant. Performance on the other two test sections was very similar between the groups.

The mean UFOV test scores for both groups in each individual experimental condition are shown in Figure 4. A two-way repeated-measures ANOVA with two within-subjects factors (UFOV subtest and auditory task presence) and one-between subjects factor (hearing loss presence) indicated a main effect of auditory task presence ($F(1,30) = 24.733$, $p < .001$, $\eta^2 = .452$) and UFOV subtest ($F(2,60) = 75.265$, $p < .001$, $\eta^2 = .715$). UFOV test scores became poorer for both groups when the auditory task was performed simultaneously, and when more visual stimuli were added to the UFOV subtests. Although the interaction between UFOV subtest and auditory task presence tended towards significance, no effect was found ($F (2,60) = 2.946$, $p = .060$, $\eta^2 = .089$). The data shows a trend for UFOV test scores to be poorer for the hearing impaired group than they were for their normally hearing counterparts when the test was performed simultaneously with an auditory task (see Figure 4). Despite this trend, no statistically significant interaction between hearing loss presence and performance was found. Measures of baseline performance on UFOV without the presence of an auditory distracter were not significantly different, although for subtest 3 (incorporating the distracter array of 47 triangles) a lower average score was noted for the hearing impaired participants (181.3 ms) than for the normally hearing group (133.4 ms), though this was not significant; $t(30) = 1.37$, $p = .183$. When controlling for the effects of cognitive differences in the participants of each group (assessed by KIPS test battery scores), there remains no significant interaction between UFOV performance and hearing loss presence.

A comparison of the change in UFOV scores as a result of auditory task engagement between normally hearing and hearing impaired individuals showed a marginal, but not significant, difference between the two groups. There was a worse performance decrement for hearing impaired participants when they were required to complete subtest 2 of UFOV in the presence of an auditory task.

The mean percentage scores for the auditory task performed as a baseline measure and during each UFOV subtest are shown in Figure 5. A main effect of the UFOV subtest on the accuracy of auditory responses was noted (F (1.709,49.574)= 7.378, $p = .03$, $\eta^2 = .203$). Mauchly's test indicated that the assumption of sphericity had been violated, χ^2 (5) = 36.873, $p > .001$, hence the Greenhouse-Geisser correction was used. Contrast analysis indicated an increasing linear effect of visual task complexity (F (1,29)= 14.57, $p = .001$, $\eta^2 = .045$), such that the accuracy of auditory responses was progressively reduced with increasing visual task demand. Although under each visual condition the mean score of the hearing impaired group was lower than that of the normally hearing group, no main effect of hearing loss presence was observed.

4. Discussion

The aim of this study was to assess the effect of auditory distraction on the performance of a complex visual task, and to test whether this effect was more pronounced in hearing impaired compared to normally hearing participants. The results show that the performance of a simultaneous auditory task degrades performance on UFOV, and that the more complex the visual task becomes, the greater the effect of the auditory distracter. These findings concur with those of Wood et al. (2006) who found that the simultaneous performance of an auditory task significantly reduced performance on a visual task analogous to UFOV, particularly when the visual task incorporated an array of visual distracters. Wood et al. (2006) argue that results such as these are of great practical importance for driving as they may be suggestive of poorer hazard and sign detection and loss of vehicle control during periods of auditory engagement. This study's results advocate that auditory task engagement whilst driving may well decrease road safety. It has been shown here that auditory distraction reduces scores for a test on which poor performance has been linked with various driving performance measures. The concurrence of these results with past research suggests that caution should be exercised with regard to complex auditory task engagement whilst driving. Indeed, given the increasing availability and use of in-car systems which function using the auditory modality, these findings are of clear practical importance. This data seems to suggest that these types of device may have an adverse effect on driving ability, if they are actively engaged with whilst on the road.

In terms of the exacerbating effect of hearing loss, the effect of the concurrent auditory task was the same for both groups. This lack of statistical significance is not likely to be due to a withdrawal from the auditory task in favour of the visual task; although visual task complexity affected auditory task scores, this effect was the same for both experimental groups. Concurrent engagement in the auditory task, did not result in any significant differences in UFOV performance between the two groups in this study. These results are in contrast to past research in this area, which found a disproportionate effect of auditory task engagement in those with hearing loss (Hick and Tharpe 2002, Hickson et al. 2010). However, since there was a trend for worse UFOV performance by the hearing impaired participants in this study (even without an auditory task) the results warrant highlighting, because it is possible that this group find visually complex environments challenging in both dual and single task conditions.

The implications of complex in-car systems operating in the auditory modality have already been discussed above. In concurrence with Hickson et al. (2010), we suggest that, this can be particularly problematic for hearing impaired drivers, if they have to engage with multiple cognitively demanding tasks in the presence of such in-vehicle systems. Further research to identify and test alternative solutions for this population is therefore warranted.

Hickson et al. (2010) noted that the degree of hearing impairment was the best predictor of overall driving ability in their study sample. Their results also suggested that mild hearing impairment is not associated with poorer driving ability in the presence of distracters. This may have been a possible reason why a statistically significant difference was not observed between the performances of the two groups in this study. Nearly half (8 out of 17) of the hearing loss group in this study had an impairment classified as mild, leaving relatively little data from those with a moderate (8 out of 17) and severe (1 out of 17) hearing impairment. Further research which examines how different levels of hearing loss affect UFOV performance in the presence of auditory distractors is therefore valuable.

An interesting trend identified in this study is the pattern of results for UFOV involving no simultaneous auditory task. A lower baseline score on subtest 3 of UFOV (incorporating visual, but no auditory distracters) was noted in the hearing impaired group compared to the normally hearing participants. This was unexpected, as it was hypothesised that extra attention to the auditory task would bring about a disturbance on UFOV in the hearing impaired sample. A lower score on a particular UFOV subtest in the absence of any auditory information cannot, therefore, be explained by this hypothesis. Interestingly, a similar phenomenon, whereby hearing impaired individuals appear to be more distracted by visual information, has been noted in past research (Thorslund et al., 2013a). Furthermore, the data presented by Hickson et al. (2010) suggests that visual distraction had a negative influence equal to that of auditory distraction on overall measured driving performance in their hearing impaired participants. However, there is no forthcoming explanation as to why this may have been the case.

Although the groups in the current study were closely matched in terms of age, the number of years of formal education undertaken, driving experience and a number of the cognitive tests undertaken, there was a significant difference found between the two groups in the reading span section of KIPS. Importantly, this effect was found in the absence of any auditory information, thus suggesting that it is related to a general inability to process complex information efficiently, rather than it stemming from a distortion of auditory information at the periphery. This finding may explain the discrepancy in UFOV subtest 3 performance between the two groups in the absence of a simultaneous auditory task. It should be noted, however, that the cognitive test battery undertaken here was not entirely diagnostic with regard to visual attention breadth, auditory processing of language, or the production of language. Indeed, this was not a general cognitive test per se, though the reading span subtest is considered to predict performance on higher-order cognitive tasks (Engle, 2002). It may be wise to incorporate alternative or supplementary measures of complex working memory span into future work (see e.g. Conway et al., 2005).

It should be noted that the results of this study do not imply that those with a hearing impairment are more at risk of vehicular crashes. However, this experiment has suggested that those with a hearing impairment may be slower to react to visual information whilst performing a cognitively demanding auditory task, or during periods where the visual scene is very cluttered. This has ramifications for driving in terms of failures of visual attention under such circumstances. During periods of auditory task performance, hazard perception, for instance, may be suboptimal, leading to an increased risk of road traffic accidents, although this was not directly tested in our study. However, those who have issues with multi-tasking may well adapt their behaviour and withdraw from the auditory task in order to increase their road safety. Indeed, Thorslund et al. (2013a; 2013b; 2014) have repeatedly observed, what they argue, is an adaptive driving style in their hearing impaired participants. Furthermore, there is a possibility that hearing impaired drivers may compensate for any negative effects of their hearing loss with more developed visual skills (e.g. Mitchell & Maslin, 2007). This appears particularly pertinent for profoundly deaf individuals, as there has been some suggestion that their visual reactions, particularly in the periphery of vision, are quicker than those of normally hearing people (Bavelier, et al., 2000; Loke & Song, 1991). Studies of the real-world driving of hearing impaired individuals would, therefore, be of great value in determining if these adaptations in behaviour are likely to be the case.

5. Conclusions

This study has shown that the simultaneous performance of a cognitively demanding auditory task and UFOV decreases performance on both respective tasks. These results are of great practical importance, as they may indicate that aspects of visual attention, related to driving performance, are compromised during periods of auditory engagement. The results may be more applicable to hearing impaired individuals, given that they recorded marginally worse performance across a number of UFOV subtests when undertaking a concurrent auditory task. It should also be noted that those with a hearing impairment showed a non-significant tendency to perform worse on subtest 3 of UFOV, even in the absence of any auditory information. This suggests that those with a hearing loss might be less able to perform complex visual tasks efficiently, even when there is no influence of sound present. Additionally, cognitive testing suggests a decrease in the working memory capabilities of hearing impaired individuals. These results bring to light interesting questions about the information processing capabilities of hearing impaired individuals. Further research in this area is required in order to improve our understanding of the effect of hearing impairment on dual-task execution, and its potential supplementary effect on driving competence.

6. References

Arlinger, S., 2003. Negative consequences of uncorrected hearing loss - a review. International Journal of Audiology 42(suppl 2), S17-2S20.

Atchley, P., & Dressel, J., 2004. Conversation limits the functional field of view. Human Factors 46 (4), 664-673.

Ball, K., Owsley, C. 1993. The useful field of view test: A new technique for evaluating age-related declines in visual function. Journal of the American Optometric Association 64(1), 71-79.

Ball, K., Owsley, C., Sloane, M.E., Roenker, D.L., Bruni, J.R. 1993. Visual-attention problems as a predictor of vehicle crashes in older drivers. Investigative Ophthalmology & Visual Science 34(11), 3110-3123.

Barreto, S.M., Swerdlow, A.J., Smith, P.G., Higgins, C.D. 1997. Risk of death from motor-vehicle injury in Brazilian steelworkers: a nested case-control study. International Journal of Epidemiology 26(4), 814-821.

Bédard, M., Weaver, B., Darzins, P., Porter, M.M. 2008. Predicting driving performance in older adults: We are not there yet! Traffic Injury Prevention 9(4), 336-341.

Bavelier, D., Tomann, A., Hutton, C., Mitchell, T., Corina, D., Liu, G., Neville, H. 2000. Visual attention to the periphery is enhanced in congenitally deaf individuals. Journal of Neuroscience 20(17), RC93.

Borg, E., Bergkvist, C., Olsson, I.S., Wikstrom, C., Borg, B. 2008. Communication as an ecological system. International Journal of Audiology 47(suppl 2), S131-S138.

British Society of Audiology, 2011. Recommended procedure: Pure-tone air-conduction and bone-conduction threshold with and without masking. British Society of Audiology, Reading.

Classen, S., Mccarthy, D.P., Shechtman, O., Awadzi, K.D., Lanford, D.N., Okun, M.S., Rodriguez, R.L., Romrell, J., Bridges, S., Kluger, B., Fernandez, H.H. 2009. Useful field of view as a reliable screening measure of driving performance in people with parkinson's disease: Results of a pilot study. Traffic Injury Prevention 10(6), 593-598.

Clay, O.J., Wadley, V.G., Edwards, J.D., Roth, D.L., Roenker, D.L., Ball, K.K. 2005. Cumulative meta-analysis of the relationship between useful field of view and driving performance in older adults: Current and future implications. Optometry and Vision Science 82(8), 724-731.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Zach Hambrick, D., Wilheim, O., Engle, R. W. 2005. Working memory span tasks: a methodological review and users guide. Psychonomic Bulletin and Review 12(5), 769-786.

Edwards, J.D., Ross, L.A., Wadley, V.G., Clay, O.J., Crowe, M., Roenker, D.L., Ball, K.K., 2006. The useful field of view test: Normative data for older adults. Archives of Clinical Neuropsychology 21(4), 275-286.

Edwards, J.D., Vance, D.E., Wadley, V.G., Cissell, G.M., Roenker, D., Ball, K.K. 2005. Reliability and validity of useful field of view test scores as administered by personal computer. Journal of Clinical and Experimental Neuropsychology 27(5), 529-543.

Engle, R. W., 2002. Working memory capacity as executive attention. Current Directions in Psychological Science 11(1), 19-23.

Gilhotra, J.S., Mitchell, P., Ivers, R., Cumming, R.G. 2001. Impaired vision and other factors associated with driving cessation in the elderly: The blue mountains eye study. Clinical and Experimental Ophthalmology 29(3), 104-107.

Green, K. A., McGwin, G., and Owsley, C. 2013. Associations Between Visual, Hearing, and Dual Sensory Impairments and History of Motor Vehicle Collision Involvement of Older Drivers. Journal of the American Geriatrics Society 61(2), 252–257.

Hällgren, M., Johansson, M., Larsby, B., Arlinger, S. 1998. Dichotic speech tests. Scandinavian Audiology 27(suppl 49), 35-39.

Hällgren, M., Larsby, B., Lyxell, B., Arlinger, S. 2001. Cognitive effects in dichotic speech testing in elderly persons. Ear and Hearing 22(2), 120-129.

Hick, C.B., Tharpe, A.M. 2002. Listening effort and fatigue in school-age children with and without hearing loss. Journal of Speech Language and Hearing Research 45(3), 573-584.

Hickson, L., Wood, J., Chaparro, A., Lacherez, P., Marszalek, R. 2010. Hearing impairment affects older people's ability to drive in the presence of distracters. Journal of the American Geriatrics Society 58(6), 1097-1103.

Ho, C., Tan, H.Z., Spence, C. 2006. The differential effect of vibrotactile and auditory cues on visual spatial attention. Ergonomics 49(7), 724-738.

Hogan, C.A., Turner, C.W. 1998. High-frequency audibility: Benefits for hearing-impaired listeners. Journal of the Acoustical Society of America 104(1), 432-441.

Ivers, R.Q., Mitchell, P., Cumming, R.G. 1999. Sensory impairment and driving: The blue mountains eye study. American Journal of Public Health 89(1), 85-87.

Loke, W.H., Song, S.R. 1991. Central and peripheral visual processing in hearing and nonhearing individuals. Bulletin of the Psychonomic Society 29(5)**,** 437-440.

Lyxell, B., Andersson, J., Andersson, U., Arlinger, S., Bredberg, G., Harder, H. 1998. Phonological representation and speech understanding with cochlear implants in deafened adults. Scandinavian Journal of Psychology 39(3), 175-179.

McCloskey, L.W., Koepsell, T.D., Wolf, M.E., Buchner, D.M. 1994. Motor-vehicle collision injuries and sensory impairments of older drivers. Age and Ageing 23(4), 267-273.

Mccoy, S.L., Tun, P.A., Cox, L.C., Colangelo, M.L., Stewart, R.A., Wingfield, A. 2005. Hearing loss and perceptual effort: downstream effects on older adults' memory for speech. Quarterly Journal of Experimental Psychology Section A - Human Experimental Psychology 58(1), 22-33.

Mitchell, T.V., Maslin, M.T., 2007. How vision matters for individuals with hearing loss. International Journal of Audiology 46(9), 500-511.

Owsley, C., 1994. Vision and driving in the elderly. Optometry and Vision Science 71(12), 727-735.

Owsley, C., Ball, K., Mcgwin, G., Sloane, M.E., Roenker, D.L., White, M.F., Overley, E.T. 1998. Visual processing impairment and risk of motor vehicle crash among older adults. Jama-Journal of the American Medical Association 279(14), 1083-1088.

Picard, M., Girard, S.A., Courteau, M., Leroux, T., Larocque, R., Turcotte, F., Lavoie, M., Simard, M. 2008. Could driving safety be compromised by noise exposure at work and noise-induced hearing loss? Traffic Injury Prevention 9(5), 489-499.

Pomplun, M., Reingold, E.M., Shen, J.Y. 2001. Investigating the visual span in comparative search: The effects of task difficulty and divided attention. Cognition 81(2), B57-B67.

Rabbitt, P.M.A. 1968. Channel-capacity intelligibility and immediate memory. Quarterly Journal of Experimental Psychology 20(3), 241-248.

Rabbitt, P.M.A. 1991. Mild hearing-loss can cause apparent memory failures which increase with age and reduce with IQ. Acta Oto-Laryngologica 476, 167-176.

Rantanen, E.M., Goldberg, J.H. 1999. The effect of mental workload on the visual field size and shape. Ergonomics 42(6), 816-834.

Shinn-Cunningham, B.G., Best, V. 2008. Selective attention in normal and impaired hearing. Trends in Amplification 12(4), 283-299.

Sims, R. V., McGwin Jr, G., Allman, R. M., Ball, K., and Owsley, C. 2000. Exploratory study of incident vehicle crashes among older drivers. Journals of Gerontology Biological Sciences and Medical Sciences 55(1): M22-M27.

Thorslund B., Ahlström, C., Peters, B., Eriksson, O., Lidestam, B., Lyxell, B. 2014. Cognitive workload and visual behavior in elderly drivers with hearing loss. European Transport Research Review. 6, 377-385.

Thorslund B., Peters, B., Herbert, N., Holmqvist, K., Lidestam, B., Black, A., Lyxell, B. 2013a. Hearing loss and a supportive tactile signal in a navigation system: effects on driving behavior and eye movements. Journal of Eye Movement Research. 5(6), 1-9.

Thorslund B., Peters, B., Lidestam, B., Lyxell, B. 2013b. Cognitive workload and driving behavior in persons with hearing loss. Transportation Research Part F: Traffic Psychology and Behaviour. 21, 113-121.

Unsworth, C.A., Wells, Y., Browning, C., Thomas, S.A., Kendig, H. 2007. To continue, modify or relinquish driving: Findings from a longitudinal study of healthy ageing. Gerontology 53(6), 423-431.

Wood, J., Chaparro, A., Hickson, L., Thyer, N., Carter, P., Hancock, J., Hoe, A., Le, I., Sahetapy, L., Ybarzabal, F. 2006. The effect of auditory and visual distracters on the useful field of view: Implications for the driving task. Investigative Ophthalmology & Visual Science 47(10), 4646-4650.

Williams, L.J., 1982. Cognitive load and the functional field of view. Human Factors 24(6), 683-692.

Williams, L.J., Lefton, L.A., 1981. Processing of alphabetic information presented in the fovea or the periphery - functional visual-field and cognitive load. Perception 10(6), 645-650.

Wingfield, A, Tun, P.A, McCoy, S.L. 2005. Hearing loss in older adulthood: What it is and how it interacts with cognitive performance. Current Directions in Psychological Science 14(3), 144-148.

Table 1 An overview of case-control studies investigating the relationship between hearing loss and driving outcomes.

Study and total sample size	**Measure of hearing loss used**	**Driving data collected**	**Outcome**
McCloskey et al. (1994) N = 683	Pure tone audiometry; speech reception thresholds; hearing aid ownership and use.	Crash resulting in a medical claim within 7 days of the road traffic accident.	Hearing aid owners and users whilst driving more likely to be involved in a crash.
Barreto et al. (1997) N = 145	Hearing loss (yes or no) obtained from health records, but no definition given.	Deaths as a result of motor vehicle injuries.	Those with hearing loss more at risk of death as a result of road traffic injury.
Ivers et al. (1999) N = 2,326	Self-reported degree of hearing difficulty.	Self-reported road traffic accidents within previous year.	Those self-reporting a severe hearing loss more likely to have had a road traffic accident in the previous year.
Sims et al. (2000) N = 174	Self-reported hearing difficulty (classified as yes or no) and hearing aid use.	Road traffic accidents within the previous five years.	No difference in risk of road traffic accident as a result of hearing loss or hearing aid use.
Gilhotra et al. (2001) N = 2,831	Self-reported degree of hearing difficulty.	Self-reported driving cessation.	Those with a severe self-reported hearing difficulty more likely to have ceased driving.
Unsworth et al. (2007) N = 538	Self-reported degree of hearing difficulty.	Self-reported driving cessation or modification to driving behaviour.	No change in driving behaviour or extra risk of cessation as a result of self-reported hearing difficulty.
Picard et al. (2008) N = 46,030	Pure tone audiometry. Only cases of normal hearing or noise-induced hearing loss included.	Motor vehicle accidents, speeding violations, and ‘all other violations’.	Risk of accident increased by hearing loss. Those with a hearing loss have a reduced risk of speeding violations, but increased risk of all other violations.
Green et al. (2013) N = 2,000	Self-reported hearing loss (yes or no).	History of a motor vehicle collision in the previous five years.	No increased risk of motor vehicle crashes in the previous five years as a result of hearing loss.

Table 2 Demographic information of the two groups included in this study

	Number of participants (Males / Females)	Age (± S.D.)	Years driver's licence owned (± S.D.)	Annual mileage (± S.D.)
Hearing impaired group	17 (8 ♂; 9 ♀)	57.88 (± 12.7)	37.94 (± 13.3)	1505 (± 640)
Normally hearing group	15 (5 ♂; 10 ♀)	51.20 (± 9.3)	34.33 (± 9.9)	1760 (± 1110)

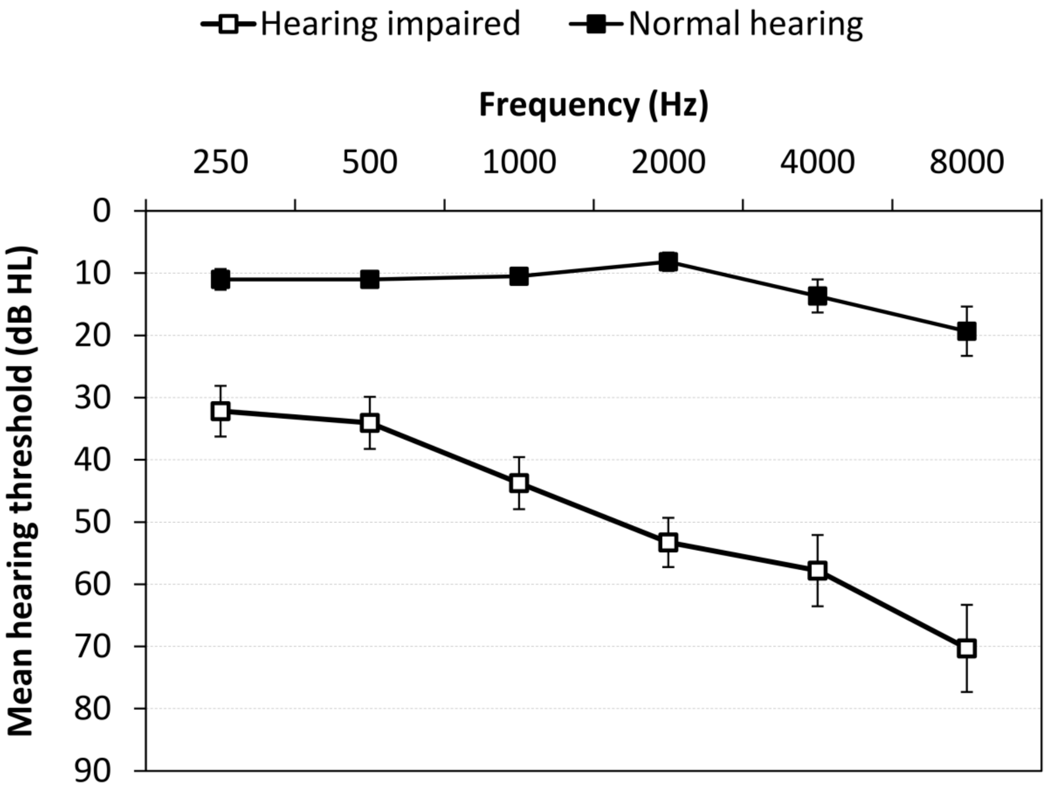

Fig 1 Mean pure tone audiometry thresholds (± standard error) for both experimental groups

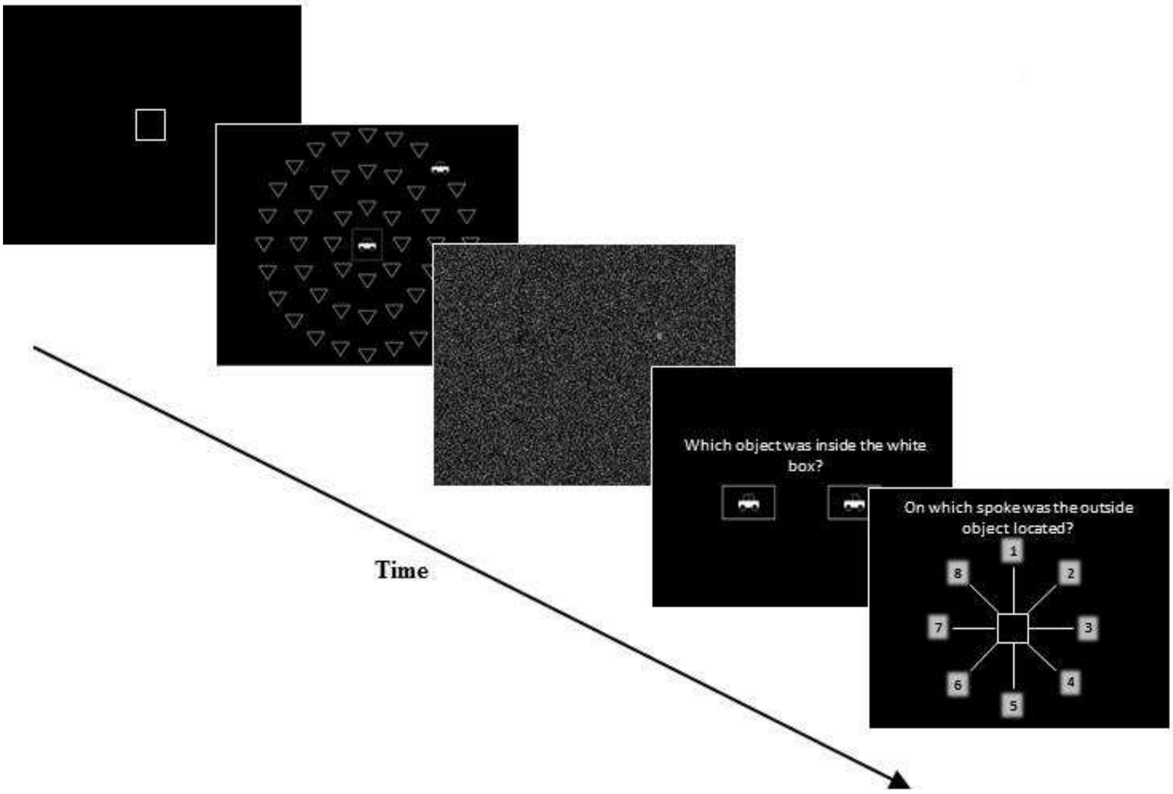

Fig 2 The presentation sequence of one trial in the UFOV software, in this case from subtest 3 (incorporating a central and peripheral target with a distracter array)

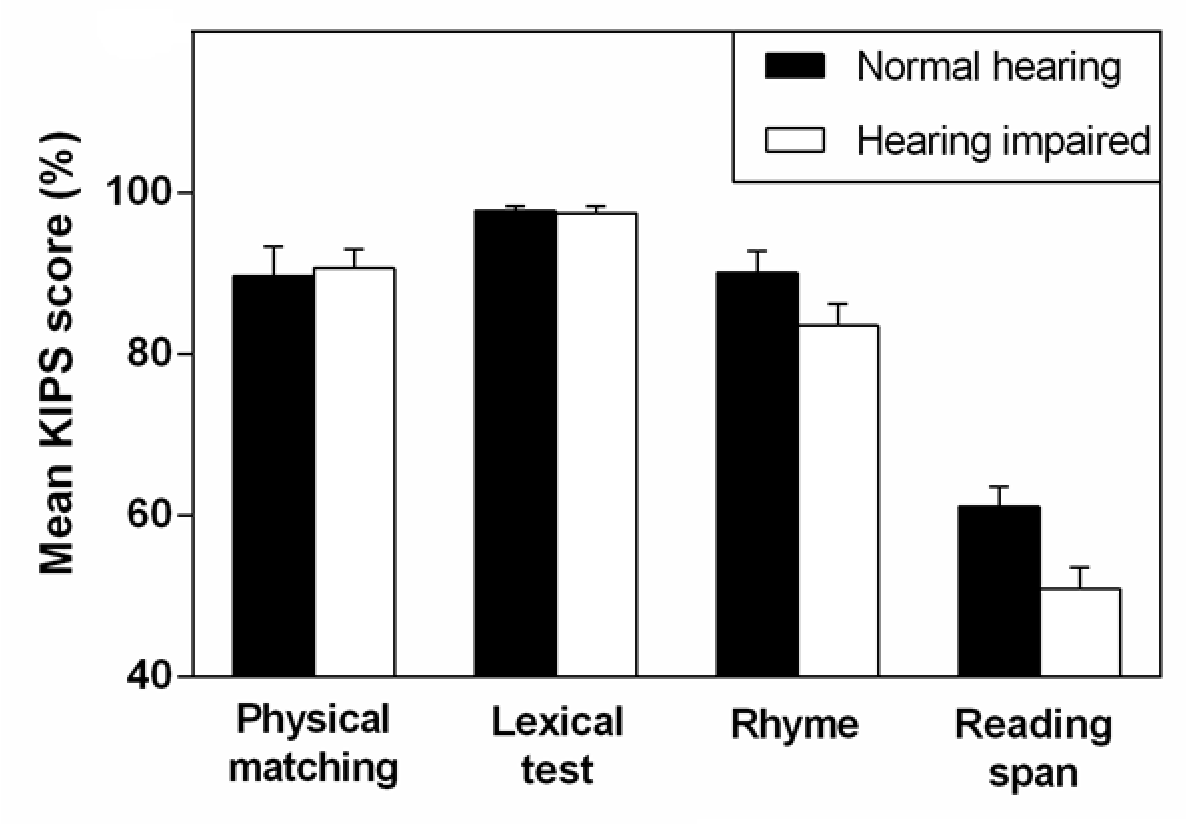

Fig 3 Mean scores (± standard error) on each individual section of the KIPS cognitive test battery

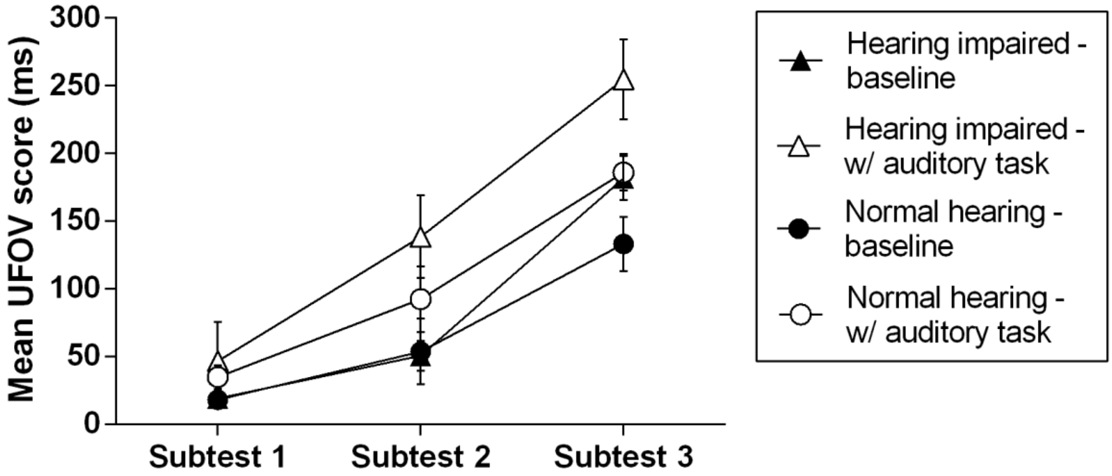

Fig 4 Mean scores for each UFOV subtest (± standard error). Scores are shown for the test being performed in isolation (black symbols) and with the auditory task present (white symbols)

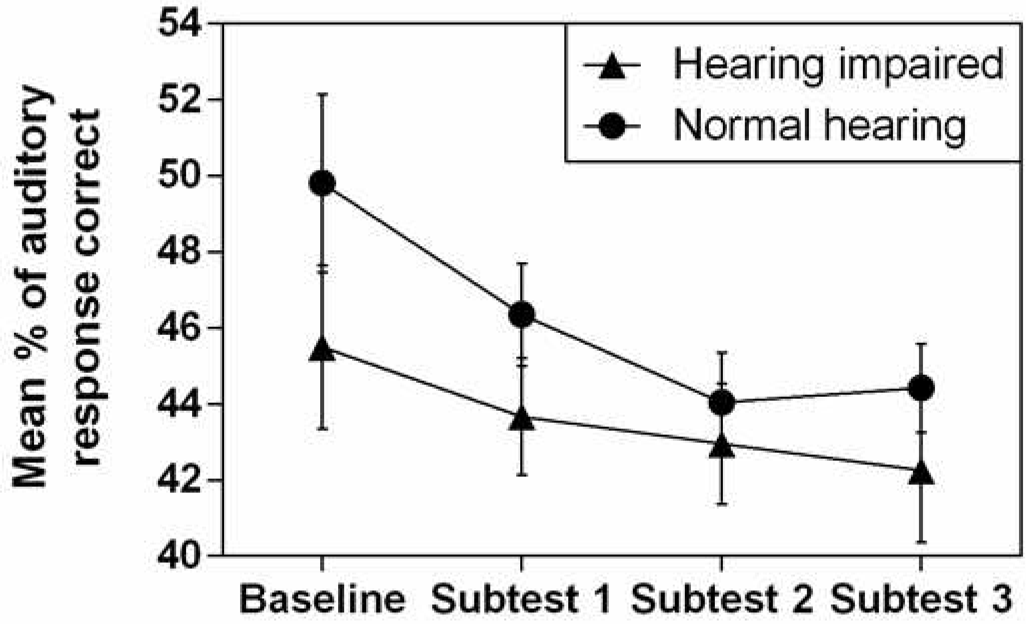

Fig 5 Mean percentage of auditory responses (± standard error) that were correct during each UFOV subtest and with the auditory task performed in isolation (baseline condition)