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Hearing Impairment Affects Older People's Ability to Drive in the Presence of Distracters

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Abbreviated title: Hearing impairment and driving

ABSTRACT

OBJECTIVES: To investigate the effects of hearing impairment and distractibility on older people's driving ability, assessed under real-world conditions.

DESIGN: Experimental cross-sectional study.

SETTING: University laboratory setting and an on-road driving test.

PARTICIPANTS: One hundred and seven community-living adults aged 62 – 88 years.

55% had normal hearing, 26% had a mild hearing impairment, and 19% had a moderate or greater impairment.

MEASUREMENTS: Hearing was assessed using objective impairment measures (pure-tone audiometry, speech perception testing) and a self-report measure (Hearing Handicap Inventory for the Elderly). Driving was assessed on a closed road circuit under three conditions: no distracters, auditory distracters, and visual distracters.

RESULTS: There was a significant interaction between hearing impairment and distracters, such that people with moderate to severe hearing impairment had significantly poorer driving performance in the presence of distracters than those with normal or mild hearing impairment.

CONCLUSION: Older adults with poor hearing have greater difficulty with driving in the presence of distracters than older adults with good hearing.

Keywords: hearing impairment, driving, vision.

1 INTRODUCTION

2 Driving is a complex everyday activity that is particularly difficult for some older people.

3 This is evidenced by the high fatal crash rates of older drivers, who are more likely than
4 younger drivers to be involved in multi-vehicle crashes in complex traffic conditions and at
5 intersections.^{1,2} Importantly, the driving environment and, in particular, the in-vehicle
6 environment are becoming increasingly complex, with vehicles being equipped with
7 sophisticated navigation and entertainment systems which, like mobile phones, may add to
8 the driver's attentional burden, distracting them from their primary task.

9

10 In line with this, recent research has highlighted the potential impact of increased distraction
11 whilst driving, particularly auditory distractions and mobile phone use.³⁻⁸ Attending to
12 auditory information has been shown to impair performance on concurrent cognitive, as well
13 as motor tasks, and the degree of this interference varies as a function of the effort required
14 by the secondary task.^{7,9-11} This may be particularly relevant for those with hearing
15 impairment, who have been shown to suffer greater distractibility in some situations.¹⁰

16

17 Previous research has suggested a link between hearing impairment and difficulties with
18 driving, either cessation or adverse events, in older people. Much of the research has relied
19 on self-reported hearing status and no measures of actual driving performance have been
20 included. For example, a significant relationship has been reported between self-reported
21 adverse driving events and hearing impairment in 589 adults over 60 years of age.¹²

22 Likewise, a study of the driving habits of 2379 current drivers over the age of 49 years found
23 that higher crash rates were associated with poorer visual acuity and moderate self-reported
24 hearing loss, especially in the right ear.¹³ Research with the same population of older drivers,
25 but including those who had stopped driving as well as current drivers, found that people who

1 reported hearing difficulties were 1.6 times more likely to have ceased driving.¹⁴ Similarly, a
2 recent study of 752 people over 65 years of age found that poor self-rated hearing was
3 associated with cessation of driving.¹⁵ Other influential factors were increasing age, marital
4 status, self-rated vision difficulties and level of independence in activities of daily living.

5
6 Further evidence concerning the possible effects of hearing impairment on driving
7 performance is available from a study that explored the role of occupational noise exposure
8 as a risk factor for motor vehicle accidents.¹⁶ Driving records were examined along with
9 pure-tone hearing threshold levels and noise exposure records of 46,030 male workers
10 employed in noisy industries in Quebec, Canada. Daily noise exposure and measured hearing
11 impairment were both associated with increased risk of traffic accidents and the odds of
12 having a traffic accident increased with greater bilateral hearing loss at high frequencies (i.e.,
13 3, 4, and 6 kHz).

14
15 This study examined the relationship between objective and self-reported measures of
16 hearing and real world measures of driving performance conducted in the presence and
17 absence of in-vehicle distracters, so as to make the level of complexity more representative of
18 everyday driving tasks. A group of older participants with a range of hearing impairment
19 were assessed and their performance while driving with no distracters and in the presence of
20 in-vehicle distracters, either visual or auditory in nature, was compared. We hypothesized
21 that hearing impairment would impact on driving in the presence of distracters, given
22 previous evidence of the greater distractibility of those with hearing impairment in some
23 situations.

24

25

1 **METHODS**

2 **Participants**

3 A total of 107 older drivers were recruited to participate from staff and students at
4 Queensland University of Technology, the University of Queensland 50+ Research Register
5 and the wider community. Participants included 59 males and 48 females, with a mean age of
6 73.5 years (S.D. = 5.6; Range = 62 - 88). All participants had binocular visual acuity that was
7 better than driver licensing standards in Australia of 20/40. Better eye visual acuity had a
8 mean of 0.01 logMAR (equivalent to 20/20) (S.D. = 0.10; Range = -0.2 - 0.3). The Mini-
9 Mental State Examination was used to give an indication of cognitive function and all but
10 two of the participants scored above the criterion level of 23 (Mean = 28.6; S.D. = 1.7;
11 Range = 21 – 30). The majority of participants had completed secondary (38.3%) or tertiary
12 education (41.1%), with only 20.6% finishing school at primary level.

13

14 All participants lived in the community and reported a range of driving experience. On
15 average, they drove 5 days of each week (S.D. = 1.7; Range = 1 – 7). The majority (72%)
16 had more than 50 years of driving experience; 21.5% had 41 to 50 years experience and the
17 remainder (6.5%) had between 20 and 40 years experience. Seventy per cent drove more than
18 60 km per week. Participants reported an average of one crash per 25 driver years. Fifteen
19 per cent of participants reported that they wore a hearing aid in one or both ears when
20 driving.

21

22 **Measures**

23 Participants attended two testing sessions, the first of which was a laboratory session where
24 demographic information was collected along with assessments of vision, cognition and
25 hearing. The second session was an assessment of driving performance on a closed road

1 circuit. The study was conducted in accordance with the requirements of the Queensland
2 University of Technology Human Research Ethics Committee. All participants were given a
3 full explanation of the experimental procedures, and written informed consent was obtained
4 with the option to withdraw from the study at any time.

5

6 *Hearing*

7 There were three measures of hearing: pure-tone audiometry, speech perception testing and
8 self-reported hearing disability. The first two tests were conducted in the quietest available
9 room in the research wing of the School of Optometry at Queensland University of
10 Technology. Pure-tone audiometry and speech perception testing were conducted using a
11 Madsen Itera II by GN Otometrics, with circumaural ME70 noise excluding TDH39 and a
12 B71 bone conductor and headband. Pure-tone air conduction thresholds were obtained in
13 both ears at 250, 500, 1000, 2000 and 4000 Hz and bone conduction was obtained at 500,
14 1000, 2000 and 4000 Hz.

15

16 Speech perception in quiet and in noise was assessed using sentence lists originally
17 developed for the Hearing in Noise Test.¹⁷ The recorded sentences were presented
18 bilaterally at each participant's most comfortable listening level in quiet and this ranged from
19 60 to 105 dB SPL (Mean = 74; SD = 9). Participants heard four lists of 10 sentences in
20 different listening conditions in the following order of increasing difficulty: 1) in quiet; 2) at
21 +10 dB signal to noise ratio (SNR); 3) at +5 dB SNR, and 4) at 0 dB SNR. The recording
22 used was of a female Australian speaker and the noise was a speech shaped broad band noise.
23 Participants receive a percentage correct word score for each list. An example sentence is:
24 "Big dogs can be dangerous". Participants received a percentage correct score for each test

1 condition based on the total number of words they correctly repeated for each of the 10
2 sentences in a list. All but one of the participants completed this assessment.

3

4 The 25 item Hearing Handicap Inventory for the Elderly (HHIE) ¹⁸ was used as a measure of
5 hearing difficulties in everyday life. The response options and scoring for each item on the
6 questionnaire are yes (4), sometimes (2), and no (0). A total score and a score for two
7 subscales (social and emotional) are calculated. The social subscale has 12 items, for
8 example, “Does a hearing problem cause you to avoid groups of people?” and the emotional
9 subscale has 13 items, for example, “Does a hearing problem cause you to be nervous?”

10 Total scores can range from 0 to 100 with higher scores indicative of greater self-reported
11 hearing disability.

12

13

14 ***Driving***

15 Driving performance was assessed on a 5 km closed-road circuit, which is representative of a
16 rural road and free of other vehicles (except for one following car). Participants drove a right
17 hand drive sedan (1997 Nissan Maxima) with an automatic transmission and power steering.

18 If participants normally wore glasses and/or hearing aids while driving, they wore these

19 during the assessment. Participants were given a practice run during which they were able to

20 familiarize themselves with the car, the road circuit and the driving tasks. The practice run

21 was identical to each test run except that it was driven in the opposite direction to the

22 recorded run, so as to minimize familiarity effects. It included driving without distraction,

23 and then with the auditory and visual distracters added separately, so that participants had the

24 opportunity to practice all components of the assessment prior to the recorded run.

25 Participants were instructed that they would be required to perform a number of concurrent

1 tasks while driving at what they felt was a safe speed, to drive in their own lane except when
2 avoiding hazards, and to drive as they normally would under the circumstances. Performance
3 was assessed by the same trained research staff for all participants, using the following
4 objective measures:

5 *Time to complete the road course.* An experimenter in the vehicle recorded the total
6 time taken to complete the circuit.

7 *Road sign recognition.* The road sign recognition task required participants to report
8 the information on any of 54 road signs located along the course (e.g., stop, give way)
9 containing a total of 77 items of information. A participant's score represents the total
10 number of correctly reported items of information.

11 *Road hazard recognition and avoidance.* Participants were required to report and
12 avoid hitting any of nine large, low-contrast foam rubber road hazards that were centred
13 across the driving lane. The road hazards were constructed from sheets of 180cm x 80cm x
14 5cm gray/brown foam rubber, with a mean reflectance of 10%. Although the hazards could
15 be felt when driven over, they had little effect on vehicle control. The position of the road
16 hazards was randomised between each lap; during any given trial, only nine of a total of 11
17 hazards were positioned on the course. Performance was measured as the number of road
18 hazards hit.

19 *Gap perception.* Nine pairs of traffic cones with variable lateral separations were also
20 positioned throughout the course. Equal numbers of cones were set to be not wide enough,
21 just wide enough and obviously wide enough for the test vehicle to pass through. Participants
22 were instructed to report if the clearance between cones was sufficient for the vehicle to pass
23 through and, if so, to attempt to do so. If the cone separation was judged to be too narrow,
24 they were instructed to drive around the cones. The separation of the cones was varied
25 between each lap. Performance was measured as the number of cone gaps judged correct.

1 *Composite driving Z score.* A composite score was also derived to capture the overall
2 driving performance of the individual participants compared with the whole group and
3 included road sign recognition, cone gap perception, course time, and the number of road
4 hazards hit as per our previous studies.^{19,20} Z scores for each of these four component driving
5 measures were determined and the mean Z score for each participant calculated to give an
6 overall score. Equal weighting was assigned for all tasks.

7
8 Participants drove the track three times: 1) without distraction, 2) with auditory distraction,
9 and 3) with visual distraction. The order of conditions was randomized. The secondary
10 distraction task required participants to verbally report the sums of numbers presented either
11 through a computer speaker (auditory distracter) or through a dashboard mounted LCD
12 monitor (visual distracter) while driving. The monitor was positioned just to the left of the
13 steering wheel on the dashboard, slightly below driver eye height. The visual task consisted
14 of the simultaneous presentation of pairs of numbers (e.g. 1 + 5) subtending between 3.5° and
15 4.8° of visual angle at the viewing distance of participants. The auditory stimuli were
16 presented at a comfortable listening level set by the participant using an adaptive procedure.
17 Pairs of numbers were presented roughly every 3.5 seconds. Performance measures for the
18 distracter tasks included the percentage of correct responses, incorrect responses and non-
19 responses.

22 **DATA ANALYSIS**

23 We first examined the association between various measures of hearing function and the
24 driving performance measures. Pure-tone average (PTAvge) hearing levels were obtained by
25 averaging 500, 1000, 2000 and 4000 Hz. Hearing loss in the better ear was classified based

1 on this average using the following criteria: ≤ 25 dB HL = normal hearing; 25.1 to 40 dB HL
2 = mild hearing loss; 40.1 to 60 dB HL = moderate hearing loss; > 60.1 dB HL = severe
3 hearing loss.^{21,22} As age was also found to be highly correlated with driving performance in
4 our sample, analyses were conducted using age as a covariate, so age-related decrements in
5 performance (potentially related to other functional domains) were accounted for. Since some
6 hearing measures showed highly skewed distributions, bivariate correlations were examined
7 using non-parametric (Spearman) correlations adjusting for age. Mixed ANOVAs were
8 conducted for each driving performance measure with the repeated measures factor of
9 distraction (None, Auditory, and Visual) and the between-subjects factor of hearing
10 (Normal/Mild versus Moderate/Severe). Measures of performance were also calculated for
11 the secondary tasks and these were analysed using the same mixed ANOVA model.

12

13 **RESULTS**

14 Hearing assessment results are summarized in Table 1. The mean better ear pure-tone
15 average was 27 dB HL (S.D. = 14.5, Range = 2.5 to 82.5). Based on the better ear pure-tone
16 average, 45% of participants had some degree of hearing impairment, however, less than 5%
17 had severe or greater loss. Other features of the participants hearing was that 78% were
18 bilaterally symmetrical, that is, had the same hearing classification in both ears. For all but
19 one of the remaining participants, there was a difference of only one classification level
20 between ears (e.g., normal in one ear and mild in the other). One participant had normal
21 hearing in one ear and a severe hearing impairment in the other. The correlation between
22 PTA_{ave} in both ears was significant ($r(105) = 0.9, p < 0.001$). Of the 48 people with better
23 ear hearing impairment, 46 had a sensorineural hearing impairment and two had a mixed
24 hearing impairment. Greater hearing impairment was associated with increasing age ($r(105) =$
25 $0.6, p < .001$), poorer speech perception scores in quiet ($r(105) = 0.5, p < 0.001$) and in noise

1 (e.g., at 0 db SNR, $r(105) = 0.6$, $p < 0.001$) and more self-reported hearing problems on the
2 HHIE ($r(104) = 0.7$, $p < 0.001$). These findings of predominantly mild to moderate bilateral
3 sensorineural hearing impairment in 45% of the sample are typical of this population.^{22,23}

4

5 Put Table 1 near here.

6

7 To determine which of the hearing function measures best related to driving performance,
8 bivariate correlations among the various measures of hearing function (i.e., hearing
9 categories, speech perception in quiet and noise, HHIE scores) and the overall driving Z score
10 were examined. No individual hearing measure significantly predicted overall driving
11 performance after controlling for age, however, as can be seen in Table 2, the objective
12 measures of hearing (pure-tone testing and speech perception testing) overall showed
13 stronger correlations with driving performance than self-reported hearing difficulties. The
14 best predictor of overall driving performance was the degree of hearing impairment in the
15 better ear. On the basis of this, participants were then split into two groups based on this
16 variable (normal or mild hearing impairment, with better ear pure-tone average ≤ 40 dB in one
17 group and moderate to severe impairment, with average > 40 dB in the other) so that it was
18 possible to examine interactions between this variable and the repeated measures variable of
19 distraction. This better ear 40 dB cut-off between groups is appropriate as the more severe
20 functional effects of hearing impairment are generally considered to occur beyond this
21 level.²⁴

22

23 Put Table 2 near here.

24

1 A 2 * 3 mixed ANOVA with the factors of hearing (normal/mild impairment versus
2 moderate/severe impairment) and distraction (none, visual or auditory) on the overall driving
3 Z scores revealed a main effect of distraction ($F(2,208) = 15.9, p < 0.001$). Overall
4 performance was better in the no distracter condition than in either of the two distracter
5 conditions, however, the visual and auditory distracter conditions did not differ significantly.

6

7 There was also a significant interaction between the level of hearing impairment and
8 distraction, ($F(2,208) = 5, p = 0.01$). As can be seen in Figure 1, among both hearing
9 impairment groups, the auditory and visual distracters resulted in poorer performance than
10 the no distracter condition, but the two distracter conditions did not differ significantly from
11 one another. The differences between the no-distracter conditions and each of the two
12 distracter conditions, however, is much larger among those with poorer hearing function,
13 suggesting that those with hearing impairment are compromised to a far greater extent, when
14 required to undertake a secondary task while driving.

15

16

Put Figure 1 near here.

17

18 A 2 * 3 mixed ANOVA with the factors of hearing (normal/mild impairment or
19 moderate/severe impairment) and distraction (none, visual or auditory) on the individual
20 driving measures revealed a significant main effect of distracter condition on two of the
21 measures: 1) the overall time to complete the course ($F(2,208) = 4.4, p = 0.013$), and 2) the
22 number of signs recognized ($F(2,208) = 30.1, p < 0.001$). The effect of distracter condition
23 was not significant for any of the other driving measures including cone gap perception or
24 hazards hit.

25

1 In terms of time to complete the course, participants took longer to complete the course in the
2 visual distracter condition than in either the no-distracter condition or the auditory distracter
3 conditions. The auditory and no-distracter conditions did not differ in terms of time to
4 complete the course. In terms of signs read (see Figure 2), participants correctly perceived a
5 greater number of road signs in the no distracter condition, less in the visual condition, and
6 least overall in the auditory condition. All pairwise differences of this main effect were
7 significant. There was also a significant interaction between hearing function and distraction
8 in terms of the effect on sign-recognition ($F(2,208) = 4, p = 0.019$). In both groups,
9 controlling for age, the auditory and visual distracters result in poorer performance than the
10 no distracter condition, but the two distracter conditions do not differ significantly, although
11 there was a marginally significant difference between the auditory and visual distracter
12 conditions in the hearing impaired group ($p = 0.08$).

13

14

Put Figure 2 near here.

15

16 To establish whether the above results might be partly influenced by performance on the
17 distracter tasks, we further analysed the proportion of distracter sums missed, as well as
18 answered incorrectly. A $2 * 2$ mixed ANOVA with the factors of hearing (normal/mild
19 impairment or moderate/severe) and distraction (visual or auditory) on each of these
20 measures revealed no significant main effects of either hearing function or distraction, and no
21 significant interaction between the factors, indicating that engagement with the task was not
22 affected by the modality of distracter presentation (i.e., auditory or visual). Overall,
23 participants answered 67% of all sums correctly.

24

25

1 **DISCUSSION**

2 Our findings indicate that moderate to severe hearing impairment in older drivers is
3 associated with worse driving performance in the presence of distracters, where the
4 deleterious effect of distracters (either auditory or visual) was greater among those with
5 moderate/severe hearing impairment than for those with normal/mild hearing impairment.
6 We argue that distracters are an integral part of everyday driving, therefore this finding has
7 important practical implications. These findings suggest that older people with hearing
8 impairment should make every effort to reduce in-vehicle distractions such as listening to the
9 radio, conversations with passengers, looking at navigation systems and mobile phone use.

10

11 This is the first study of older drivers that has included objective measures of hearing and an
12 on-road assessment of driving performance and it is the first to identify an adverse affect of
13 hearing impairment on aspects of driving performance. Previous studies have used self-
14 reported hearing impairment and/or driving and few associations have been found. Thus,
15 advice about the influence of hearing on driving should be based on objective measures and,
16 in particular, on pure-tone audiometry results in the better ear as this was the best predictor of
17 driving performance overall in this sample.

18

19 Participants' degree of hearing impairment had the greatest effect on the driving component
20 skill of sign recognition when driving in the presence of distracters. Performance showed the
21 same pattern as the overall driving score, with no effect of hearing when there were no
22 distracters and then a decline in performance with distraction. It has previously been reported
23 that when people are driving in complex situations, drivers appear to prioritize vehicle control
24 tasks like lane keeping,^{25, 26} while shedding other tasks like reading and naming signs.²⁰ This
25 finding is also in line with reports that a person's peripheral Useful Field of View is reduced

1 in the presence of distracters²⁷ and the fact that older people have more accidents at
2 intersections¹ where sign recognition is critical. Interestingly, there was also a trend for
3 poorer sign recognition performance when the distracter was auditory, rather than visual, and
4 this warrants further investigation. It may be that the combination of the auditory activity of
5 listening and adding up numbers with reading and naming signs, both of which have
6 phonological loads to some extent, was more effortful than the combination of a visual
7 distracter and the sign recognition task.

8
9 Overall, these findings are consistent with those from other studies of older adults with
10 hearing impairment in which the sensory-perceptual deficit of hearing impairment negatively
11 influences performance on cognitive tasks.^{10,28} Referred to as the effortfulness hypothesis,²⁹
12 the decrease in performance on a primary task is believed to occur because the extra effort
13 associated with listening to and understanding a degraded auditory signal deprives resources
14 from other cognitive processes. While the aim of this study was to examine the effects of
15 hearing alone in a population of otherwise normal older adults, it might also be informative in
16 future studies to examine whether the effects described here also interact with other areas of
17 function, in particular mental health and cognitive impairment, which also may impose
18 constraints on cognitive processes.

19
20 In conclusion, we found that moderate and severe hearing impairment in older people has a
21 negative effect on driving performance in complex situations. These findings provide further
22 evidence of how changes in low level sensory acuity can influence cognitive processes that
23 support complex behaviors like driving. The results suggest that older drivers with moderate
24 and severe hearing impairment are at greater risk of unsafe driving in the presence of
25 distracters and this needs to be taken into account when designing new technologies and

1 when providing driving advice to these individuals regarding driving situations to avoid.
2 Knowledge of the potential interactions are of importance in an increasingly complex driving
3 environment where older adults are driving well into old age, and auditory displays and in-
4 vehicle devices are becoming more prevalent in most modern vehicles.

5

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12

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Table 1. Summary of Participant Characteristics (n = 107)

		Mean	SD	Minimum	Maximum	Count	Percent
Age		73.5	5.6	62.0	88.0		
Gender	Male					59	55.1%
	Female					48	44.9%
Number of medical conditions		3.8	2.1	0	10		
Highest education level reached	Primary					22	20.6%
	Secondary					41	38.3%
	Tertiary					44	41.1%
Binocular visual acuity in logMAR		0.01	0.10	-0.18	0.32		
Mini Mental State Examination score		28.6	1.0	21.0	30.0		
Better ear PTA _{ave} in dBHL		27.0	14.5	2.5	82.5		
Better ear hearing impairment	Normal (0-25 dB)					59	55.1%
	Mild impairment (25.1 – 40 dB)					28	26.2%

Moderate impairment				17	15.9%
(40.1 – 60 dB)					
Severe impairment				3	2.8%
(>60dB)					
Speech perception in quiet	97.7	10.9	0.0	100.0	
Speech perception +10db SNR	88.7	15.1	0.0	100.0	
Speech perception +5db SNR	73.3	24.0	0.0	100.0	
Speech perception +0db SNR	43.5	24.7	0.0	94.1	
HHIE total score	11.0	13.7	0.0	60	
HHIE emotional subscale score	4.8	7.4	0.0	30	
HHIE social subscale score	6.2	6.9	0.0	30	

LogMAR = logarithm of the minimum angle of resolution

PTAvge in dBHL = pure-tone average in decibel hearing level

SNR = signal to noise ratio

HHIE = Hearing Handicap Inventory for the Elderly

Table 2. Non-parametric Correlations (Spearman's rho) Between Hearing Measures and Overall Driving Ability (Z score of mean performance)

	Spearman rho	Partial Spearman rho *
Right ear hearing category	-0.22	-0.05
Left ear hearing category	-0.32	-0.13
Better ear hearing category	-0.33	-0.16
Worst ear hearing category	-0.24	-0.04
HHIE total score	-0.15	-0.03
HHIE emotional subscale	-0.13	-0.04
HHIE social subscale	-0.16	-0.03
Speech perception in quiet	0.08	-0.1
Speech perception +10db SNR	0.26	0.01
Speech perception +5db SNR	0.25	0.07
Speech perception 0db SNR	0.32	0.03

*controlling for age

HHIE = Hearing Handicap Inventory for the Elderly

SNR = signal to noise ratio

Figure 1. Mean performance Z score for the driving task in each condition as a function of hearing status. Error bars are ± 1 standard error.

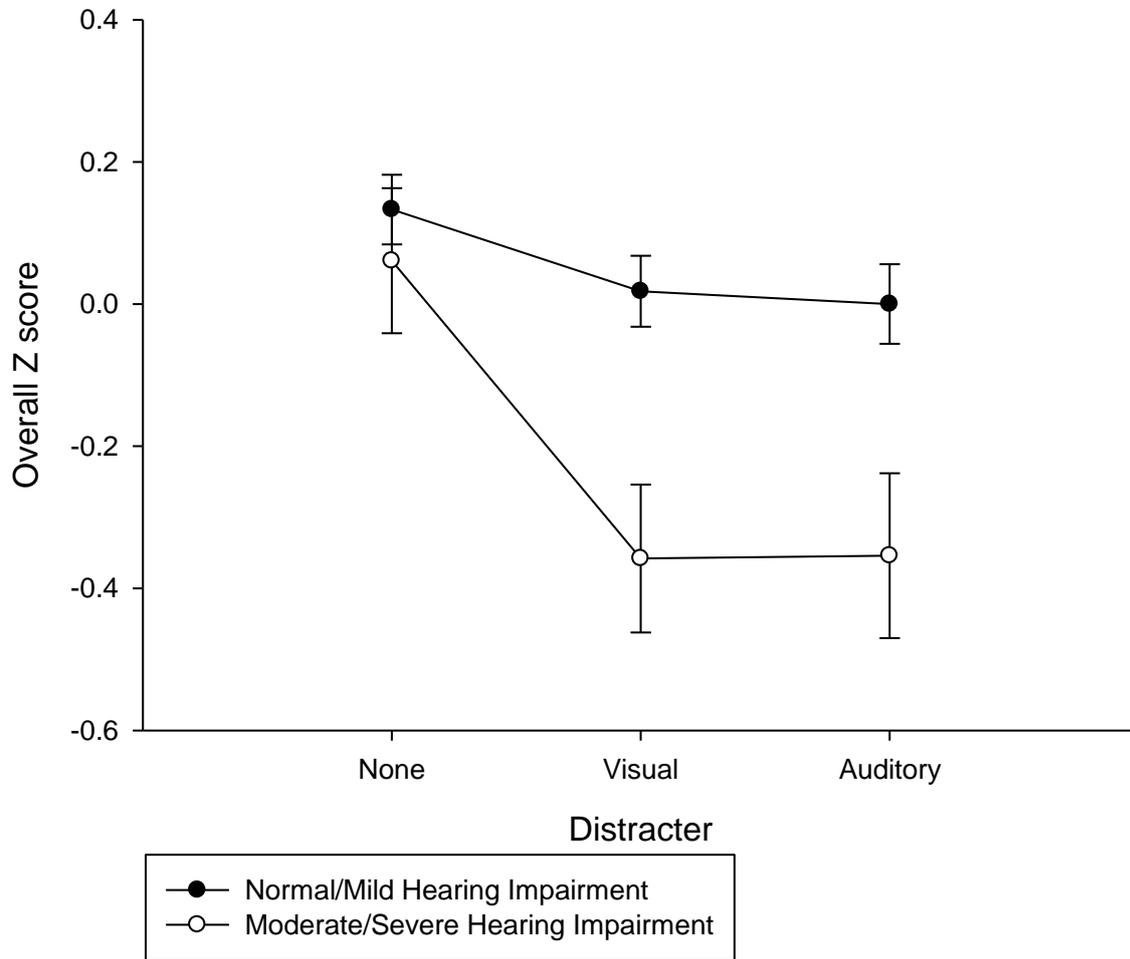


Figure 2. Mean number of road signs correctly recognised in each condition as a function of hearing status. Error bars are ± 1 standard error.

