Tinnitus and Sleep Difficulties after Cochlear Implantation
Supplemental Digital Content 2

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HEARING AID USE AND SPEECH PERCEPTION

Associations between tinnitus characteristics and sleep difficulties were also analyzed separately with four ancillary groups, including the potential candidates for cochlear implantation (Candidate group), to estimate the potential independent and combined contributions of hearing aid (HA) use and poor speech perception. Post-hoc contrasts were also analyzed to test the effect of HA use on tinnitus persistence in the cochlear implant (CI) group. Ancillary groups were selected based on reported HA use and speech reception thresholds (SRTs) as measured with the Digit Triplets Test (DTT), and labelled as follows:

Group	**Device**	**Speech perception**	**SRT range (dB)**
HA-Poor (Candidate)	Hearing Aid	'Poor'	[0, +8)
HA-Good	Hearing Aid	'Good'	[-12, -5.5]
UA-Poor	Unaided	'Poor'	[0, +8)
UA-Good	Unaided	'Good'	[-12, -5.5]

Note that in the above nomenclature, 'HA-Poor' is the equivalent label for the Candidate group where SRT scores were ≥ 0 dB and the score of +8 dB (the maximum possible value) was excluded to avoid the inclusion of any results that could be attributed to non-compliance or equipment failure. The 'Good' speech perception category, defined as SRTs ≤ -5.5 dB, was based on derived associations between audiometric thresholds and DTT scores obtained from normative SRT data in a sample of young normal-hearing listeners (Dawes et al. 2014). The SRT of -12 dB was the minimum possible value in the DTT.

RESULTS

Participant characteristics

Table S1 lists the participant characteristics and Table S2 lists the self-reported measures for ancillary groups. The CI group is included to facilitate comparisons with the findings in the main manuscript. There were more males than females in all but UA-Good ancillary group. There were more older adults across all the ancillary groups with the majority of participants clustering in the 55-69 age bands. The proportion of the HA users who had 'Good' speech perception ('HA-Good') and who reported hearing difficulties was large (96%) and similar to that of the Candidate group ('HA-Poor'). A similar proportion of participants in the HA-Good group also reported difficulties following conversations in noise (92%) despite the fact that they still appeared to be able to perform the DTT at adverse SNRs (mean SRT -7.8 dB, Table S1). When compared to the aided participants, hearing difficulties were less common among the unaided participants (UA-Poor 61%; UA-Good 22%), as were difficulties following conversations in noise (UA-Poor 68%; UA-Good 32%). The average SRT was +2.9 dB and -8.1 dB in the UA-Poor and UA-Good group, respectively. Nearly a half (48%) of the 191 CI users reported using a HA most of the time (data from three users were missing).

Tinnitus profile and Sleep difficulties

Figure S2 shows the prevalence of self-reported tinnitus characteristics and sleep difficulties in the ancillary groups. The CI group was included to facilitate a comparison with the findings in the main manuscript. Tinnitus was more prevalent among those who used a HA and had poor speech perception than among those who had either characteristic alone ($p = 0.006$). Tinnitus persistence was more common in HA users than unaided participants ($p < 0.001$; HA/UA *OR* = 2.16, 95% conf. int. 1.81–2.56). However, post-hoc contrasts showed no effect of HA use on tinnitus persistence in the CI group ($p = 0.98$). In fact, the persistence of tinnitus reported by CI users was similar to that of unaided participants ($p = 0.39$; CI/UA *OR* = 0.83, 95% conf. int. 0.54–1.28; Fig. S2).

A comparison of tinnitus distress across the ancillary groups revealed a significant effect of group ($p < 0.001$) and a significant association between tinnitus distress and tinnitus persistence ($p < 0.001$; Frequent/Infrequent *OR* = 4.07, 95% conf. int. 3.72–4.46). However, unlike between the CI and Candidate groups, the differences in the level of tinnitus distress between ancillary groups remained significant even after controlling for persistence ($p < 0.001$). Further analyses revealed a significant effect of speech perception ($p < 0.001$; Poor/Good *OR* = 2.89, 95% conf. int. 2.17–3.86) and HA use ($p < 0.001$; HA/UA *OR* = 1.45, 95% conf. int. 1.19–1.75), but no interaction ($p = 0.76$).

The levels of sleep difficulties were similar across all five groups including the CI group ($p = 0.31$). Participants with tinnitus were more likely to report sleep difficulties than those without ($p < 0.001$; *OR* = 1.29, 95% conf. int. 1.24–1.36). Excluding CI users, there was no difference in the level of sleep difficulties across the ancillary groups ($p = 0.44$) and no association between sleep difficulties and tinnitus persistence ($p = 0.622$). However, the association between sleep difficulties and tinnitus distress was significant ($p < 0.001$; Upsetting/Slight *OR* = 1.32, 95% conf. int. 1.18–1.48).

DISCUSSION

Tinnitus Persistence and Distress

HA users were more likely to have tinnitus and their tinnitus was also more persistent than that of unaided participants. This finding is in agreement with the assumption that HA users had a clinically-diagnosed hearing loss, which is a major risk factor for tinnitus (Nondahl et al. 2011). Moreover, a comparison of the HA and UA groups showed a significant association with tinnitus distress even after controlling for tinnitus persistence, and a significant effect of speech perception and HA use on tinnitus distress. These findings suggest that tinnitus distress is not purely driven by tinnitus persistence where the degree of hearing impairment differs significantly; i.e. whether by impaired hearing sensitivity indicated by HA use or impaired hearing function due to poor speech perception in noise. This was not observed in the CI and Candidate group comparison where the degree of hearing impairment was presumed to have been similar.

The level of tinnitus distress appeared to be influenced by both speech perception and HA use in the ancillary groups even when tinnitus persistence was controlled for. As in the case of tinnitus persistence, this result is consistent with the current consensus that hearing loss is a major risk factor for tinnitus. Therefore, higher levels of hearing impairment would be expected to lead to higher levels of tinnitus intrusiveness and distress, and less likely be dependent on the frequency of occurrence of tinnitus symptoms.

Sleep Difficulties

The high prevalence of sleep difficulties was not specific to the CI and Candidate groups. Taken together, the present findings suggest that sleep difficulties were not associated with, and possibly independent of, the severity of tinnitus symptoms whether measured in terms of persistence or emotional distress. In fact, the association with emotional distress was only found when comparing the HA and UA groups. This finding could have been due to the fact that unlike for the CI and Candidate groups, tinnitus etiologies and symptoms could have been more distinct between HA and UA groups, at least in part due to different degrees of hearing impairment. These differences in the severity of their tinnitus symptoms could therefore have had a different degree of impact on reported sleep difficulties.

In summary, the present comparison shows a high prevalence of sleep difficulties in people with tinnitus and that the use of a hearing device does not appear to lead to a systematic improvement in sleep difficulties. The lack of improvement may possibly be due to their devices being switched off at night time which allows their tinnitus to revert back to its original loudness.

Hearing Difficulties

Hearing difficulties were highly prevalent in both HA groups. Even though speech perception was categorized as ‘good’, hearing difficulties were reported in 96% and difficulties following conversations in noise in 92% of participants in HA-Good group. These prevalence figures are similar to the Candidate group (HA-Poor, Table S2) and consistent with the assumption that participants in both HA groups had a clinically-diagnosed hearing loss. However, despite the large proportion of self-reported difficulties following conversation in noise, the average SRT was about 11.3 dB lower in the HA-Good than in the

Candidate group, which suggests a relatively large proportion of false positives in the self-report measure (Moore et al. 2014). As expected, hearing difficulties were less common among unaided than aided participants (including CI users) with 61% in the UA-Poor and 22% in the UA-Good groups. Similarly, the number of self-reported difficulties following conversation in noise was lower in the unaided groups with 32% in the UA-Group being the lowest estimate across all groups. This trend is consistent with the prediction that hearing sensitivity would likely have been more acute in the unaided than the aided groups, and best in the unaided group with 'normal' hearing function.

REFERENCES

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TABLE S1. Participant characteristics (missing data excluded in %). SRT: Speech Reception Threshold; SD: Standard Deviation. CI: cochlear implant; HA: hearing aid; UA: unaided; Good: SRT ≤ -5 dB in the better ear; Poor: 0 ≥ SRT < +8 dB in the worse ear.

Group		**CI**		**Candidate (HA-Poor)**		**HA-Good**		**UA-Poor**		**UA-Good**	
n (total)		194		211		1,141		394		97,696	
Gender	male	115	(59%)	130	(62%)	611	(54%)	209	(53%)	44,247	(45%)
Age band in years	40-44	17	(9%)	5	(2%)	42	(4%)	23	(6%)	12,338	(13%)
	45-49	15	(8%)	8	(4%)	60	(5%)	33	(8%)	14,743	(15%)
	50-54	19	(10%)	9	(4%)	98	(9%)	36	(9%)	16,226	(17%)
	55-59	28	(14%)	28	(13%)	165	(14%)	46	(12%)	17,765	(18%)
	60-64	47	(24%)	60	(29%)	386	(34%)	109	(28%)	22,586	(23%)
	65-69	68	(35%)	101	(48%)	390	(34%)	147	(37%)	14,038	(14%)
Deprivation	Quintile 1	46	(24%)	58	(28%)	461	(41%)	71	(18%)	37,666	(39%)
	Quintile 2	43	(22%)	46	(22%)	259	(23%)	64	(16%)	21,962	(22%)
	Quintile 3	37	(19%)	37	(18%)	175	(15%)	65	(16%)	17,228	(18%)
	Quintile 4	36	(19%)	41	(19%)	163	(14%)	124	(32%)	14,330	(15%)
	Quintile 5	30	(16%)	28	(13%)	81	(7%)	69	(18%)	6,362	(6%)
	Missing	2		1		2		1		148	
Neuroticism score	Mean (SD)	4.25	(3.60)	4.98	(3.37)	4.58	(3.26)	5.01	(3.32)	4.38	(3.26)
SRT in dB (SD)	40-44	--		4.6	(3.4)	-7.2	(0.8)	3.0	(2.3)	-7.2	(0.9)
	45-49	--		1.9	(1.6)	-6.9	(0.7)	3.3	(2.9)	-7.1	(0.8)
	50-54	--		4.4	(2.7)	-7.0	(0.9)	3.1	(2.6)	-7.1	(0.8)
	55-59	--		3.8	(2.4)	-6.8	(0.8)	3.2	(2.6)	-7.0	(0.8)
	60-64	--		3.1	(2.2)	-6.8	(0.8)	2.6	(2.6)	-6.9	(0.8)
	65-69	--		3.1	(2.5)	-6.7	(0.7)	2.2	(2.6)	-6.8	(0.7)

TABLE S2. Self-reported measures of hearing, tinnitus type and sleep difficulty (missing data excluded in %). CI: cochlear implant; HA: hearing aid; UA: unaided; Good: SRT ≤ -5 dB in the better ear; Poor: 0 ≥ SRT < +8 dB in the worse ear.

Characteristic	Category	Subcategory	CI		Candidate (HA-Poor)		HA-Good		UA-Poor		UA-Good	
Difficulty hearing	Yes		164	(87%)	210	(>99%)	1,091	(96%)	227	(61%)	19,995	(22%)
	No		25	(13%)	1	(<1%)	47	(4%)	147	(39%)	72,328	(78%)
	Missing		5		0		3		20		5,413	
Difficulty hearing in noise	Yes		161	(87%)	204	(97%)	1,045	(92%)	260	(68%)	30,157	(32%)
	No		24	(13%)	7	(3%)	91	(8%)	124	(32%)	65,149	(68%)
	Missing		9		0		5		10		2,390	
Tinnitus type	Current	Frequent	38	(21%)	78	(39%)	342	(30%)	70	(18%)	6,775	(7%)
		Infrequent	47	(27%)	35	(17%)	167	(15%)	59	(16%)	7,614	(8%)
	Past		25	(14%)	27	(13%)	133	(12%)	52	(14%)	10,818	(11%)
	Never		67	(38%)	63	(31%)	487	(43%)	197	(52%)	70,689	(74%)
	Missing		17		8		12		16		1,800	
Tinnitus distress	Upsetting	Severely	13	(12%)	16	(11%)	37	(6%)	17	(10%)	667	(3%)
		Moderately	27	(25%)	52	(37%)	149	(23%)	53	(30%)	3,676	(15%)
	Slight	Slightly	43	(39%)	43	(31%)	283	(44%)	61	(35%)	12,143	(48%)
		Not at all	26	(24%)	29	(21%)	169	(27%)	44	(25%)	8,537	(34%)
	Missing		85		71		503		219		72,673	
Sleep difficulty	Usual	Usually	50	(26%)	69	(33%)	351	(31%)	128	(33%)	26,993	(28%)
		Sometimes	87	(46%)	105	(50%)	547	(48%)	179	(46%)	46,256	(47%)
	Rare	Never/rarely	53	(28%)	37	(17%)	242	(21%)	84	(21%)	24,389	(25%)
	Missing		4		0		1		3		58	

Figure S2. Characterization of tinnitus (A-C) and sleep difficulties (D) in the ancillary groups. Cochlear implant group was included to compare with the findings in the manuscript. Percentages represent the age-gender standardized rates with missing data excluded. Dashed lines indicate ancillary groups and shaded areas represent the proportion of participants reporting the presence of tinnitus, higher tinnitus persistence, related distress or frequency of sleep difficulties. CI: cochlear implant; HA: hearing aid; UA: unaided. Good: SRT = [-12, -5] dB; Poor: SRT = [0, +8) dB.