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Quality of Life and Auditory Performance in Adults with Asymmetric Hearing Loss

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Key Words
Asymmetric hearing loss · Binaural hearing · Glasgow Health Status Inventory · Quality of life · Speech, Spatial and Qualities of Hearing Scale

Abstract
We evaluated the relationship between binaural hearing deficits and quality of life. The study included 49 adults with asymmetric hearing loss (AHL), and 11 adult normal-hearing listeners (NHL) served as controls. Speech reception thresholds (SRT) were assessed with the French Matrix Test. Quality of life was evaluated with the Speech, Spatial and Qualities of Hearing Scale (SSQ) and the Glasgow Health Status Inventory. Speech recognition in noise was significantly poorer for AHL subjects [–0.12 dB signal-to-noise ratio (SNR) in dichotic (with speech presented to the poorer ear and noise to the better ear), –1.72 dB in diotic and –6.84 dB in reverse-dichotic conditions] compared to NHL (–4.98 dB in diotic and –9.58 dB in dichotic conditions). Scores for quality-of-life questionnaires were significantly below norms. Significant correlations were found between the SRT for the dichotic condition and the SSQ total score ($r = -0.38$, $p = 0.01$), and pure-tone average thresholds for both groups.

Introduction

Binaural hearing is the normal hearing process used to localise sounds and may also serve to aid segregation of speech from noise backgrounds in adverse listening conditions. The beneficial effects of binaural hearing are based upon three mechanisms. The first two mechanisms, binaural loudness summation and binaural release from masking (or 'squelch'), reflect central processing, whereas the third, the head shadow effect, is explained by listening through two ears separately. These mechanisms rely on two acoustic cues: the interaural time difference and the interaural level difference. The advantages of binaural hearing over monaural hearing have been well described previously [Colburn et al., 2006; Firszt et al., 2008].

Asymmetric hearing loss (AHL), defined as an interaural, pure-tone average (PTA) difference (0.5, 1, 2 and 4 kHz) of more than 15 dB HL [Noble and Gatehouse, 2004], induces reduced abilities to localise sound in the horizontal plane and discriminate speech in noise [Wie et al., 2010]. Giolas and Wark [1967] reported as early as 1967 that hearing disabilities occur for people with hearing asymmetry. An AHL has generally been left untreated for diverse reasons, but mainly due to unsatisfactory treatment solutions [Dwyer et al., 2014]. Nevertheless, Chisolm et al. [2007] stated that AHL may have a knock-on effect in terms of quality of life. This is usually defined as one's emotional, physical or social well-being, including the ability to perform tasks of everyday life.

AHL also affects children's quality of life: Borton et al. [2010] showed that children with AHL encounter significant social functioning disabilities (i.e. ability of a person to interact normally in society). These children also present higher rates of grade failures compared to their normal-hearing peers and often have cognitive deficits [Bess and Tharpe, 1984; Lieu, 2004].

There are a limited number of studies on quality of life in adults with AHL. Parving et al. [2001] characterised hearing disability experienced by a large and varied set of hearing-impaired adults with AHL before any hearing rehabilitation (e.g. surgery). The authors reported no significant difference for general health perception and social functioning between the hearing-impaired group and an age-matched population. Conversely, Newman et al. [1997], by means of a quality-of-life questionnaire (Hearing Handicap Inventory for Adults), investigated the self-perception of hearing handicap. Based on the results from the questionnaire, the authors concluded that subjects with AHL reported having a hearing handicap, with large variability in responses unrelated to the degree of hearing loss. This conclusion supports the idea that the audiogram alone cannot reflect precisely the subjective hearing handicap or that certain individuals may cope better with AHL than others. More recently, a study by Dwyer et al. [2014] concluded that subjects relying on only one ear, even at normal-hearing threshold, encounter disabilities in everyday listening and communication.

The relationship between quality of life and speech recognition in noise in AHL subjects has not been clearly established. Therefore, we hypothesised that a decreased ability to recognise speech in different spatial configurations of background noise may impact quality of life and that the impact may increase with the degree of hearing loss.

In the present study, we combined two approaches: (1) a standardised, adaptive speech-in-noise test to investigate speech recognition in spatially separated noise, the French Matrix Test [Jansen et al., 2012] in addition to the standard, pure-tone audiogram that fails to predict accurately speech-in-noise recognition deficits [Killion and Niquette, 2000], and (2) two quality-of-life question-

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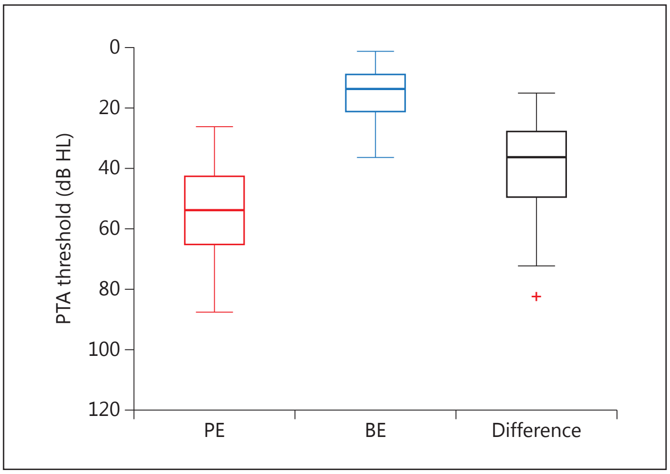

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Fig. 1. AHL hearing thresholds. PTA of the PE and the BE for the AHL group and difference between ears. Lines are medians, box limits 25th–75th percentiles and error bars confidence limits (49 AHL).

naires: a hearing-specific questionnaire, the Speech, Spatial and Qualities of Hearing Scale (SSQ) [Gatehouse and Noble, 2004] and a generic one, the Glasgow Health Status Inventory (GHSI) [Gatehouse, 2000].

Materials and Methods

Subjects. Forty-nine adults with AHL were enrolled (27 females and 22 males, mean age 47 years, ranging from 20 to 70 years). The only inclusion criterion was AHL, ranging from mild to severe or profound in order to have a representative AHL population and to evaluate the impact of the degree of interaural asymmetry. Mean PTA (0.5, 1, 2 and 4 kHz) hearing loss in the better ear (BE) was 14 dB HL (SD = 8.59) and in the poorer ear (PE) 57.72 dB HL (SD = 20.06; fig. 1). Subjects were recruited from the patient population referred to our centre. Inclusion criteria were not restricted to a unique aetiology; 13 subjects had been diagnosed with acoustic neuroma in the PE, 25 had otosclerosis and 11 chronic otitis sequelae. In addition, all AHL subjects were non-users of hearing aids or other hearing rehabilitation devices. The control group comprised 11 normal-hearing listeners (NHL; 3 males and 8 females) with a binaural hearing threshold below 20 dB HL for octave frequencies between 125 and 8 kHz. Their mean age was 40 years (ranging from 32 to 61 years) with no particular relationship between age and PTA or aetiology. Thus, thresholds for the BE in AHL subjects were similar to those for both ears in NHL. Both AHL and NHL were French native speakers.

Procedures. A GN Otometrics Madsen Itera 2 audiometer with TDH-39 headphones was used for pure-tone audiometry. The French Matrix Test was performed in the sound field in a calibrated sound booth room. Speech and noise signals were generated by a PC running the OMA software (Oldenburg Measurement Application, www.hoertech.de) and presented via loudspeakers and amplifier (Studio Lab, SLB sat 200). The French Matrix Test was used with adaptive measurements; thus, the speech signal was set at 65 dB SPL and the background noise fluctuated. Furthermore, all NHL and 8 AHL subjects were evaluated for localisation ability. Subjects were presented short, white-noise bursts (20–20 kHz, 500 ms) from a 7-loudspeaker frontal array that spanned –90° to 90° (30° spacing) in the sound field. Subjects were asked to identify the speaker location eliciting the signal. Responses were recorded as the localisation angle of error and reported as the average root mean square (RMS) error for each group.

Pure-tone audiometry was performed followed by the French Matrix Test and the localisation ability test; afterwards, the self-administered SSQ and GHSI questionnaires were distributed.

The French Matrix Test is an adaptive and a closed-set sentence test that uses 50 well-known words in French. Each sentence has the same syntactic structure: name – verb – number – object – colour; for instance, *'Félix dessine six vélos bleus' ('Felix draws six blue bikes').* The background noise is a stationary long-term average speech spectrum noise that was generated by superimposing all 280 sentences [Jansen et al., 2012].

The French Matrix Test was used in sound field testing conditions to determine the speech reception threshold (SRT) in noise in three conditions, as presented in figure 2: the dichotic condition ($S{-}60°_{PE}N{+}60°_{BE}$) with the signal presented to the PE (indicated by the pure-tone audiogram) and the noise to the contralateral BE; the diotic condition (S0°N0°) with both the signal and the noise presented from the loudspeaker located in front of the subject, and the reverse-dichotic condition ($N{-}60°_{PE}S{+}60°_{BE}$) with the signal presented to the BE of the subject and the noise to the PE. A sheet with all the written possible answers was provided to the subject. Subjects were asked to repeat any words that they heard. In all three conditions, the SRT was measured in terms of dB signal-to-noise ratio (SNR) yielding a 50% correct word score.

Data Analysis. Where data were not normally distributed (Kolmogorov-Smirnov, $p < 0.05$) comparisons between NHL and AHL were made using a non-parametric, bootstrap technique to generate 95% confidence intervals (95% CI; 1,000 samples; bias corrected and accelerated 95% CI; $\alpha = 0.05$) [Carpenter and Bithell, 2000]. This study was conducted according to the principles stated in the Declaration of Helsinki (2013) and was approved by the Purpan Hospital Ethical Committee.

Results and Discussion

Speech Reception Thresholds. Group SRT data for each listening condition are shown in figure 2. For the NHL group (black box plots), mean SRT levels were –4.98 dB (SD = 0.79) in diotic and –9.59 dB (SD = 1.53) in both dichotic and reverse-dichotic conditions. Within the AHL population (grey box plots), SRT levels were –0.12 dB (SD = 3.64) in dichotic, –1.72 dB (SD = 2.50) in diotic and –6.84 dB (SD = 3.17) in reverse-dichotic conditions. Mean differences between AHL and NHL groups were 9.13 dB for the dichotic condition, 3.25 dB for diotic and 3.07 dB for reverse-dichotic conditions (all differences $p < 0.05$ according to bootstrap 95% CI). The poorer SRT for the AHL group can be explained by inferior perception of the two binaural cues (interaural level and time differences) that are strongly affected in AHL subjects [Bronkhorst and Plomp, 1989] and may also be explained by a reduced auditory acuity to code intensity [van Schijndel et al., 2001]. Ten AHL subjects had a severe to profound hearing loss in the PE (potential candidate for implantation). Mean dichotic SRT for these subjects was significantly poorer than for the remaining AHL study cohort (3.05 vs. –0.93 dB, $p < 0.05$ according to bootstrap 95% CI).

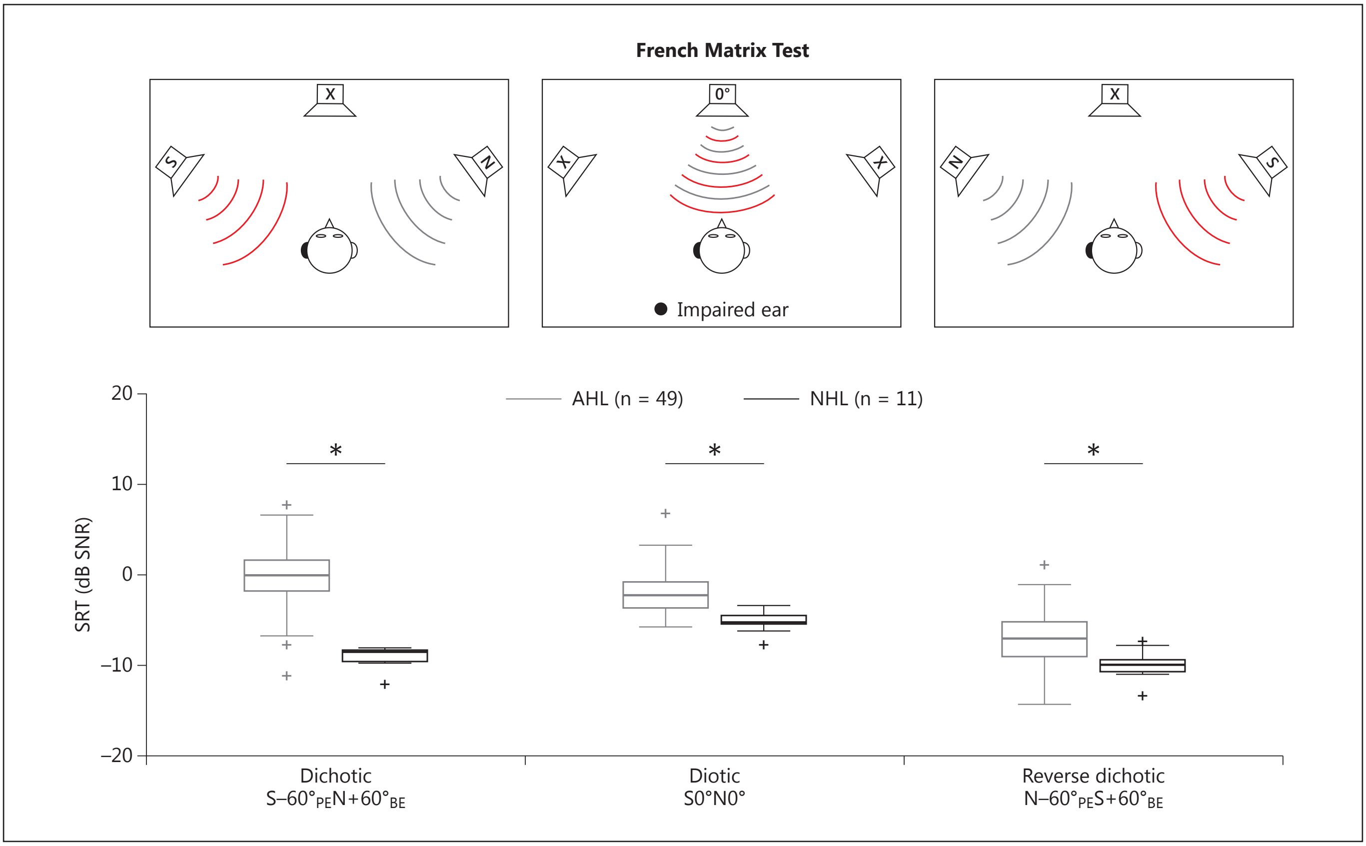

Fig. 2. SRT in sound field in three conditions in the control group (NHL; black box plots) and the AHL group. Lines are medians, box limits 25th–75th percentiles and error bars confidence limits (49 AHL and 11 NHL).

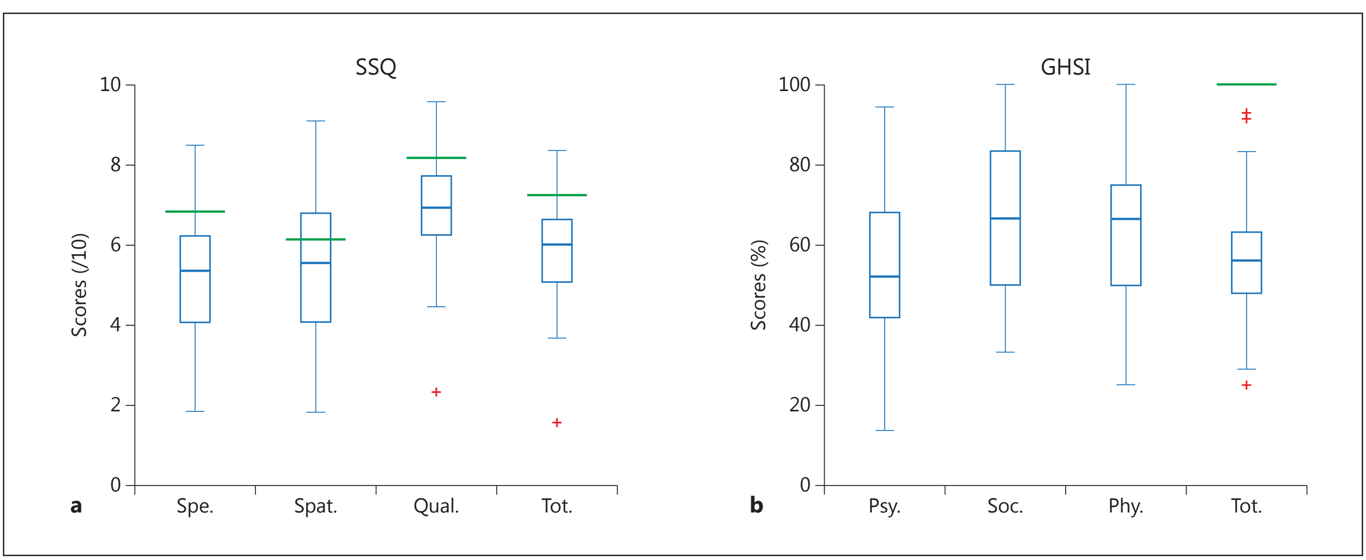

Fig. 3. SSQ (**a**) and GHSI scores (**b**). For the SSQ, speech (Spe.), spatial (Spat.) and qualities of hearing (Qual.) subscale scores and total scores (Tot.) are shown. For the GHSI, psychology (Psy.), social support (Soc.) and physic health (Phy.) subscores and mean total scores (Tot.) are depicted. Green solid lines in each panel express the cut-off limits where a score below this limit was considered as a handicap. Lines are medians, box limits 25th–75th percentiles and error bars confidence limits (49 AHL).

Table 1. Correlations: p values uncorrected for multiple comparisons

	SRT vs. SSQ				SRT vs. GHSI		
		r	p			r	p
Dio.	Spe.	–0.15	0.2327	Dio.	Psy.	0.02	0.8273
	Spat.	–0.02	0.8310		Soc.	–0.25	0.0488
	Qual.	–0.15	0.2278		Phy.	0.00	0.9581
	Tot.	–0.10	0.4312		Tot.	–0.03	0.8095
Dicho.	Spe.	–0.40	0.0016	Dicho.	Psy.	–0.02	0.8685
	Spat.	–0.32	0.0117		Soc.	–0.31	0.0146
	Qual.	–0.32	0.0116		Phy.	–0.01	0.4471
	Tot.	–0.38	0.0025		Tot.	–0.09	0.4898
Rev.	Spe.	–0.19	0.1450	Rev.	Psy.	0.07	0.5809
	Spat.	–0.13	0.3155		Soc.	–0.17	0.1872
	Qual.	–0.08	0.5261		Phy.	0.05	0.6935
	Tot.	–0.16	0.2218		Tot.	0.01	0.9104

	PTA vs. SSQ and GHSI and SRT				PTA vs. SSQ and GHSI and SRT		
		r	p			r	p
PTA: PE	GHSI Tot.	–0.04	0.72	Diff.	GHSI Tot.	0.03	0.8007
	SSQ Tot.	–0.34	0.0079		SSQ Tot.	–0.36	0.0041
	Dicho.	0.58	0.0001	Diff.	Dicho.	0.35	0.006
PTA: BE	GHSI Tot.	–0.16	0.2185				
	SSQ Tot.	–0.06	0.6227				
	Dicho.	0.32	0.011				

Diotic (Dio.), dichochotic (Dicho.) and reversed dichotic (Rev.) are the three listening conditions for the French Matrix Test. The GHSI subscales are psychology (Psy.), social support (Soc.) and physic health (Phy.). Diff. = Difference in the PTA threshold: PE – BE.

Quality-of-Life Questionnaires. Results of the quality-of-life questionnaire are given in figure 3. For the SSQ (left panel), the cut-off limits (2 SD below the mean) [Demeester et al., 2012] for the NHL group were 6.84 for the speech recognition subscale, 6.14 for the spatial hearing subscale, 8.18 for the qualities of hearing subscale and 7.25 for the total score. Significant deficits were seen for AHL subjects in all three subscales: speech recognition (n = 49, 95% CI: 4.71–5.63), spatial hearing (n = 49, 95% CI: 4.97–5.96) and qualities of hearing (n = 49, 95% CI: 6.52–7.28). Total scores were also found to be significantly lower (n = 49, 95% CI: 5.46–6.21) than the cut-off limit for NHL. Based on the SSQ total subscale scores, more than 75% of the AHL population experienced a hearing disability. A review of the literature [Noble and Gatehouse, 2004; Douglas et al., 2007] suggests similar results. For the remaining 25% of our AHL cohort, closer approximations to scores achieved for the NHL were observed. No significant correlation was determined between outcomes and subject characteristics such as age, duration of deafness, onset of hearing loss or aetiology. Our findings are in agreement with the study results reported by Olsen et al. [2012].

The score for NHL in a state of full health on the GHSI for each subscale and total was 100%. GHSI total scores for the AHL subjects were significantly below 100% (n = 49, mean 56.8%, range 49.5–64.0%). Thus, the AHL group reported a lower perception of the general quality of life compared to the NHL cohort. This is consistent with the findings reported by Parving et al. [2001].

In both questionnaires, the self-perception of the quality of life by the AHL population was mostly ranked to indicate a perceived 'handicap'. As reported by Newman et al. [1997], our data set presented large variability across subjects that may be partly explained by some AHL subjects having adapted to their hearing loss over the years.

Correlations. To further examine the relationship between SRT and outcome for the quality-of-life measures, correlation analysis was performed (table 1). After the Bonferroni correction, only the SRT for the dichotic condition appeared to be significantly related to the quality-of-life measures. Significant negative correlations were found between the dichotic SRT and the SSQ total score (n = 49, r = –0.38; p_{cor} = 0.01) and with each of the SSQ subscale scores: speech (n = 49, r = –0.40; p_{cor} = 0.006), spatial hearing (n = 49, r = –0.32; p_{cor} = 0.047) and qualities of hearing (n = 49, r = 0.32; p_{cor} = 0.047). A trend towards significance for the correlation between dichotic SRT and the GHSI social support scale (n = 59, r = –0.31; p_{cor} = 0.0584) was noted. As stated above, a deficit in the SNR required to achieve the SRT for AHL subjects was largest for the dichotic condition (~9 vs. ~3 dB for diotic and reverse dichotic) and, thus, was the most sensitive measure.

Multiple regression analysis was performed for the SSQ, GHSI or SRT with BE and PE PTA thresholds as independent variables (table 1). PTA hearing thresholds for PE and BE were significantly, positively correlated with the dichotic SRT: BE: $F(1, 44) = 4.93$, $p < 0.05$, and PE: $F(1, 44) = 15.3$, $p < 0.001$, adjusted $r^2 = 0.35$. Co-

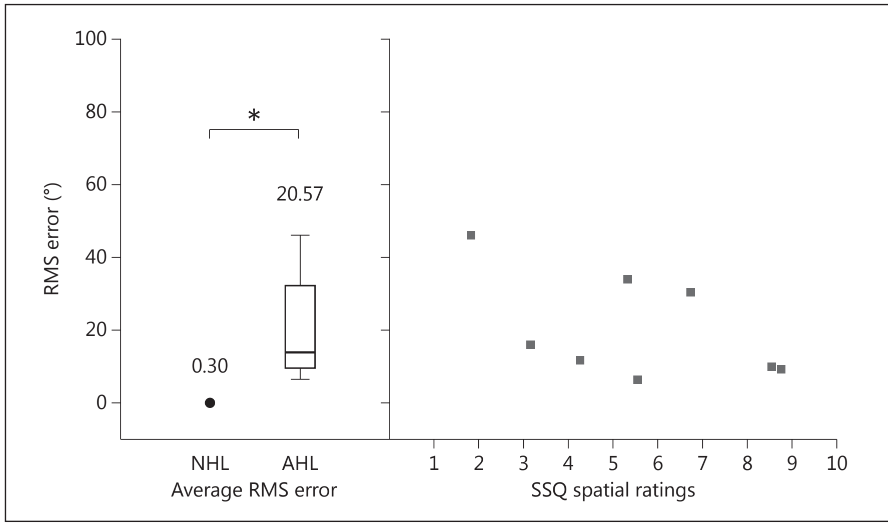

Fig. 4. Localisation ability and SSQ spatial scores. The left panel depicts both NHL and AHL group localisation ability scores in RMS (8 AHL and 11 NHL). The right panel shows the SSQ spatial scores for 8 AHL subjects.

efficients for PE and BE were ~0.11, indicating an additive effect of 1 dB on SRT per 9 dB of PTA HL. The 10 AHL subjects with severe-to-profound hearing loss had an SRT difference of 12.6 dB compared to the NHL population; thus, SRT and PTA thresholds were strongly related.

The BE PTA threshold was also positively correlated with diotic SRT: BE: $F(1, 44) = 5.16$, $p < 0.05$, and PE: $F(1, 44) = 1.57$, nonsignificant, adjusted $r^2 = 0.13$. Similar to dichotic SRT, 1 dB of diotic SRT corresponded to ~11 dB of PTA HL. There were no significant correlations between PTA thresholds and reverse dichotic SRT, presumably because the BE received the speech signal and the noise signal received at the PE could be ignored. Thus, the level of hearing loss in both ears seemed to affect binaural release of masking; however, loudness summation and head shadow appeared less affected.

Only one other effect approaching significance for a negative correlation was observed; between PTA for PE and SSQ total score: BE: $F(1, 44) = 0.135$, $p > 0.05$, and PE: $F(1, 44) = 4.99$, $p < 0.05$, adjusted $r^2 = 0.08$. This is consistent again with the study reported by Olsen et al. [2012].

In this study, we have shown that a decrease in binaural processing capability (measured by SRT) for AHL subjects impacts their perceived quality of life and that the impact increased with the degree of hearing loss. The audiogram alone failed to predict accurately the subjective handicap for AHL subjects [Killion and Niquette, 2000] and, therefore, the SRT measure is clinically useful. Based on our results, the dichotic SRT might be sensitive enough to measure the consequences of the hearing impairment. The dichotic SRT was only modestly correlated ($r = -0.38$) with the SSQ total score, suggesting that other confounding factors might have an influence on the subjective speech-in-noise recognition ability measured with the SSQ, such as tinnitus [Mertens et al., 2013] or brain reorganisation [Scheffler et al., 1998].

The results of the localisation ability testing are demonstrated for the NHL control group and a subset of 8 subjects in the AHL group in figure 4. Testing in the larger AHL subgroup has not been possible to date due to clinical time constraints. As demonstrated, localisation in the horizontal plane is significantly impaired for the AHL subgroup. This is consistent with findings reported by Van Wanrooij and Van Opstal [2004]. The average RMS error was 0.3° (SD = 1.26°) for our NHL group and 20.57° (SD = 14.46°) for the AHL subgroup (fig. 4) suggesting a significant difference between the groups (Student's $t = 3.32$, $p < 0.05$). To gain more insight into how decreased binaural sensitivity might affect the localisation ability, an analysis of the correlation between the dichotic SRT and the RMS of the AHL group was performed. A strong, significant correlation ($n = 8$, $r = 0.95$, $p = 0.0011$) was found, suggesting a negative impact of AHL upon the localisation ability. A trend towards significance was also observed for a negative correlation ($n = 8$, $r = -0.61$, $p = 0.115$) between the SSQ spatial subscale score and the RMS error. Due to the small number of AHL subjects, no definitive conclusion can be drawn for the AHL population at large. Thus, RMS error on a localisation test is most likely a useful complementary test to assess functional deficits experienced by individuals with AHL.

Conclusion

In conclusion, AHL subjects have binaural hearing deficits that present a handicap to their everyday quality of life. Furthermore, the dichotic SRT test appeared to be the most reliable criterion to screen individuals and to determine the impact of their AHL. We also observed a correlation between the dichotic SRT test results and the localisation error, which was displayed by a subset of AHL subjects in our study cohort, indicating that the latter might also be a sensitive criterion to evaluate a decrease in binaural sensitivity. This study supports the need for therapeutic solutions for AHL subjects.

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Disclosure Statement

N.V. and C.J. are employees of Cochlear France SAS.

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