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The Validation of the Spatial Hearing Questionnaire

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Abstract

Objectives—Subjective questionnaires are informative in understanding the difficulties faced by patients with hearing loss. Our intent was to establish and validate a new questionnaire that encompasses situations emphasizing binaural hearing. The Spatial Hearing Questionnaire is a self-report assessment tool utilizing eight subscales representing questions pertaining to the perception of male, female, and children's voices, music in quiet, source localization, understanding speech in quiet, and understanding speech in noise.

Design—The Spatial Hearing Questionnaire, composed of 24 items, is scored from 0–100. It was administered to 142 subjects using one or two cochlear implants. Speech perception and localization abilities were measured, and the Speech, Spatial and Other Qualities (SSQ) questionnaire was completed to evaluate validity of the questionnaire. Psychometric tests were done to test the reliability and factor structure of the Spatial Hearing Questionnaire.

Results—Results showed high internal consistency reliability (Cronbach's $\alpha = 0.98$) and good construct validity (correlations between the Spatial Hearing Questionnaire and other test measures, including the SSQ, were significant). A preliminary factor analysis revealed scores loaded on three factors, representing the following conditions: localization, speech in noise and music in quiet, and speech in quiet, explaining 64.9, 13.0, and 5.3% of the variance, respectively. Most of the questionnaire items (12/24) loaded onto the first factor which represents the subscale related to source localization. Mean scores on the Spatial Hearing Questionnaire were higher for subjects with bilateral cochlear implants over subjects with a unilateral cochlear implant, consistent with other research and supporting construct validity.

Conclusions—The Spatial Hearing Questionnaire is a reliable and valid questionnaire which can be completed independently by most patients in about 10 minutes. It is likely to be a valuable tool for clinicians and researchers to measure spatial hearing abilities.

Introduction

Hearing-care professionals are continually striving to minimize communication difficulties experienced by their patients with hearing impairment. Hearing-aid devices, such as hearing aids and cochlear implants, are available for this purpose and have improved dramatically over the years to help patients with hearing loss communicate effectively and remain active in their communities. Along with efforts to improve hearing devices, efforts to better characterize the degree of handicap and disability that results from hearing impairment have been made over the years (e.g. Zurek 1993; MacKeith & Coles 1971; Colburn, Zurek, & Durlach 1987; Peissig & Kollmeier 1997; Tyler et al. 2006a, b; Vershuur et al. 2005). Questionnaires have been developed for this purpose to more specifically report the situations faced by listeners with hearing impairment (e.g. Noble 1998; Ventry and Weinstein 1982; Walden et al. 1984; Cox and Alexander 1995, 1999, 2001; Gatehouse 1999; Noble 2006). Despite multiple

questionnaires examining patient satisfaction, hearing-aid benefit, and many other aspects of hearing loss, there are a limited number of questionnaires that encompass the realm of situations that rely on binaural hearing abilities, or the ability to utilize hearing from two ears. Spatial hearing is characterized by hearing in the sound field (but not necessary with two ears). Binaural hearing is hearing which involves both ears and is typically thought to be enhance our abilities of sound localization, speech understanding in noise with the target and the noise from different locations, and the impression that sound is three-dimensional.

Noble, Ter-Horst & Byrne (1995) developed a questionnaire addressing disability and handicap associated with impaired localization and other binaural hearing abilities. The 38-item questionnaire was divided into three sections: section I, localization disability; section II, localization handicap; and section III, speech hearing disability. The questionnaire was administered to 10 subjects with normal hearing and 104 subjects with unilateral or bilateral hearing aids and responses were scored on a four-point scale (“almost always”, “often”, “sometimes”, and “almost never”). Results showed that 1) the subjects with hearing loss had significantly more difficulty localizing sound than listeners with normal hearing; 2) handicapping effects reported by the subjects with hearing impairment, although minimal, were related to experiences of confusion of sounds in busy places, subsequent loss of concentration, and a desire to escape these challenging situations; and 3) subjects with hearing loss reported significantly poorer speech understanding, especially in group conversations and competing noise contexts. The authors also found that self-reported localization ability was significantly correlated with speech hearing abilities.

Psychometric evaluation for the localization disabilities and handicaps questionnaire (Noble, Ter-Horst & Byrne 1995) was conducted by Ruscetta et al. (2005). In this study, sections I (localization disability) and II (localization handicap) of the questionnaire were administered to a cohort of 20 subjects with normal hearing, 20 with profound hearing loss in one ear, and 10 with bilateral hearing loss of varying degrees. The authors noted that construct validity of the questionnaire was established since significant differences were found between the subjects with normal hearing and the subjects with hearing impairment for sections I and II of the questionnaire. Internal consistency reliability was assessed and a strong interrelationship was found between the items for section I and section II. Previously reported results by Flamme (2001) agreed well with those reported in this study by Ruscetta et al. (2005) for section I of the questionnaire. Finally, subjects completed the questionnaire a second time, three weeks after the first administration, and test-retest reliability was highly significant.

Based on the work of Noble, Ter-Horst & Byrne, the Speech, Spatial and Qualities of Hearing Scale (SSQ) (Gatehouse and Noble 2004; Noble and Gatehouse 2004; Noble and Gatehouse 2006) was developed to further study the relationship of disability and handicap to hearing experience across a wide variety of listening domains. The SSQ contains 49 questions, and was designed and validated based on a clinician-patient interview. The clinician rates each response on a scale from 0 to 10. The SSQ is composed of three subscales: 1) *Speech hearing*, which consists of competing sounds, the visibility of other talkers, and the number of people involved in a conversation; 2) *Spatial hearing* or directional and distance judgments; and 3) *Other qualities* such as segregation of sounds, recognition, clarity/naturalness, and listening effort.

One-hundred fifty three subjects using hearing aids were evaluated with the SSQ (Gatehouse and Noble 2004; Noble and Gatehouse 2004) and, although no factor analysis was done, the authors demonstrated that all 49 SSQ items were positively intercorrelated. In addition, they showed that the 3 subscales represent distinct domains of hearing ability, and that patients with asymmetrical hearing loss performed significantly worse than patients with symmetrical hearing loss in many situations, especially on the spatial hearing subscale. Finally, Noble and

Gatehouse (2006) investigated the effects of bilateral versus unilateral hearing aid use as measured with the SSQ. They divided subjects up into 3 groups: 144 were unaided, 118 were fit with one hearing aid, and 42 were fit with two hearing aids (aids were used for at least 6 months during their study). Results showed that subjects using one hearing aid reported more benefit over unaided subjects in several domains, including directional hearing, hearing speech in more demanding contexts (i.e., divided or rapidly switching attention), clarity and naturalness of speech, and segregation of sounds. Benefit with two hearing aids exceeded benefit with one hearing aid when subjects were asked to rate their 1) ability to hearing speech in more demanding contexts, 2) ability to judge distance and movement direction of sound, and 3) overall listening effort. The authors concluded that binaural hearing aids “offer advantage in demanding and dynamic contexts”, arguing that this has implications for improving the social competency and emotional wellbeing for an individual.

Here we describe the development of the Spatial Hearing Questionnaire. We began this process in the late 1990s, before we were aware that the SSQ was also under development. Our intent was to create a questionnaire that was particularly sensitive to spatial hearing abilities. Additionally, we expected that our questionnaire would differentiate patient performance among bilateral and unilateral cochlear implant and hearing aid users, particularly in situations where spatial hearing was emphasized. Support for this hypothesis comes from Noble and Gatehouse (2006), where bilateral hearing aid users reported advantages over unilateral hearing aid users in more demanding and dynamic listening situations, and from the literature surrounding bilateral cochlear implantation, where the advantages of two cochlear implants are well documented, specifically providing better speech understanding in noise and ability to localize sound over one cochlear implant (Tyler et al. 2002; Van Hoesel et al. 2003; Laszig et al. 2004; Nopp et al. 2004; Verschuur et al. 2005; Litovsky et al. 2006; Tyler et al. 2007). The purpose of the present study is to describe the sensitivity and psychometric property of the Spatial Hearing Questionnaire, and show its validity, reliability and perform a preliminary analysis of its factor structure.

Materials and Methods

The Spatial Hearing Questionnaire consists of 24 questions (see Appendix). Patients independently score each question on a scale from 0–100, where 0 indicates the situation is very easy and 100 indicates the situation is very difficult. We designed the questionnaire to represent eight different characteristics that are likely to be important in binaural hearing:

1. Male voices (items 1, 5, 9, 13, and 17)
2. Female voices (items 2, 6, 10, 14, and 18)
3. Children’s voices (items 3, 7, 11, 15, and 19)
4. Music (items 4, 8, 12, 16, and 20)
5. Source localization (items 13 through 24)
6. Understanding speech in quiet (items 1, 2, 3, and 4)
7. Understanding speech in noise with target and noise sources from the front (items 5 through 8)
8. Understanding speech in noise with spatially separate target and noise sources (items 9 through 12)

A total score is also obtained by combining scores from all 24 questions.

Subjects

All subjects were participants of the Iowa Adult Cochlear Implant Program from approximately 2001 to 2007. A total of 142 subjects participated in this study, 77 females and 65 males. There were 42 subjects with bilateral implants (6 were sequentially implanted and 36 were simultaneously implanted) and 100 subjects with unilateral cochlear implants. None of the subjects with a unilateral cochlear implant used a hearing aid post-operatively. A diverse number of implant types were included in this study, as seen in Table 1.

We began routinely administering the Spatial Hearing Questionnaire in 2001 to our subjects with cochlear implants. However, because of clinic time constraints and drop outs, not all subjects received the questionnaire. Subjects with 12 months or more of cochlear implant experience were included in this analysis.

Test Measures

We compared subject's scores on the Spatial Hearing Questionnaire to various speech perception measures on as many of the 142 subjects as was possible. If tests were collected at multiple sessions, only the most recent, closely matched data point to the collection of the Spatial Hearing Questionnaire was selected. In an attempt to document differences in the number of subjects across test measures, *n* is reported individually for each test below.

The following tests were used:

1. The Consonant-Nucleus-Consonant (CNC) monosyllabic word test was presented in quiet, in the sound field at 70 dB SPL(C) (Tillman and Carhart 1966). Using recorded materials, two lists of 50 CNC words were presented and lists were randomized across subjects. This test was scored by percent correct words repeated by the subject, ranging from 0 (poor) to 100 (excellent). A total of 124 subjects out of 142 were tested with CNC words (89 had a unilateral cochlear implant and 35 had bilateral cochlear implants).
2. The Hearing In Noise Test (HINT) was presented in quiet at 70 dB SPL(C) in the sound field using recorded materials (Nilsson, Soli, and Sullivan 1994). Although the HINT sentence test was originally developed to be presented with background noise, this test has been implemented into the clinical and research protocols of cochlear implant centers to assess sentence recognition abilities in quiet (Firszt 2004; Gifford 2008). Four lists of 10 sentences each were presented and lists were randomized across subjects. The HINT sentences were scored by percent correct and range from 0 (poor) to 100 (excellent). HINT sentences were collected with 121 subjects (95 had a unilateral cochlear implant and 26 had bilateral cochlear implants).
3. An adaptive spondee word test presented in background noise was used to evaluate speech recognition abilities in noise. This test was adapted from Hawley, Litovsky, and Colburn, 1999, and is referred to as the Recognition of Multiple Jammers (see Tyler et al. 2006b for more details). This test utilized an 8-loudspeaker array spanning 108° in front of the subject. An adaptive spondee word was presented from one of two loudspeakers (placed either $\pm 8^\circ$ from 0° azimuth) in front of the subject. The spondee words were spoken by a female-talker and the talker was the same voice in each trial. Simultaneously, two jammers were presented to each side of the listener, located at either $+54^\circ$ and -38° azimuth, or at -54° and $+38^\circ$ azimuth. The two jammers presented on each side of the listener consisted of both a male-talker and a female-talker in each trial. The actual talkers varied from trial to trial. In this test, the listener's task was to report the target spondee word. At the conclusion of the test, the signal-to-noise ratio at which the subject could correctly identify 50% of the target words was determined. The better the signal-to-noise ratio (i.e., more negative), the

better the subject was able to separate the target word from the jammers. Forty-eight subjects were tested with the multiple jammer test (28 had a unilateral cochlear implant and 20 had bilateral cochlear implants).

4. A localization test, referred to as Everyday Sounds Localization, was administered to assess subjects' ability to localize sound. Stimuli consisted of 16 everyday sounds (i.e. glass breaking, a knock at the door, child laughing, etc.) and eight loudspeakers, each spaced 15.5° apart, forming an 108° arc in front of the subject, were used to present the sounds (see Dunn, Tyler and Witt 2005 for a more detailed description of this test). The 16 everyday sound stimuli were each presented at 70 dB(C) six times randomly from one of the eight speakers. Subjects were asked to identify the speaker number from which the sound originated. A low score on this test (i.e. RMS error of 10–20°) would represent good localization abilities. Chance performance is approximately 40° RMS error. Sixty-three subjects out of the total 142 were tested using the everyday sounds localization test (29 had a unilateral cochlear implant and 34 had bilateral cochlear implants).
5. The SSQ was administered to a total of 139 subjects (99 unilateral cochlear implant users and 40 bilateral cochlear implant users) (Gatehouse and Noble 2004). Subjects completed all items from the three subscales of the SSQ and ratings for each item varied on a scale from 0 (less able) to 10 (more able). Responses were averaged across the subscales to give an average SSQ score. In addition, responses to the second subscale of the SSQ were examined separately to investigate how this subscale related to the Spatial Hearing Questionnaire. This subscale was intended to reflect binaural hearing abilities.

As a supplementary evaluation of the Spatial Hearing Questionnaire, we examined the results of 26 subjects before and after receiving their cochlear implant(s). Of the 26 subjects who were evaluated with the Spatial Hearing Questionnaire pre-operatively, 17 used bilateral hearing aids, 5 used a hearing aid in one ear, and 4 were unaided. Thirteen of the 26 subjects were implanted with a unilateral cochlear implant and 13 were implanted with bilateral cochlear implants. After 12 months of cochlear implant use, the Spatial Hearing Questionnaire was re-administered to all 26 subjects. The mean sentence recognition score for the 26 subjects before implantation was 17.2% (SE=3.9, SD=18.6) and the mean score after implantation was 89.6% (SE=2.3, SD=11.0).

Results

Subjects' ages ranged from 18 to 89 years with the average age at 54.2 (SE=1.8, SD=15.8) years for female subjects and 55.8 (SE=1.9, SD=15.4) years for male subjects (see Figure 1). A Pearson correlation coefficient was calculated to compare the age of the subjects to their Spatial Hearing Questionnaire scores. A non-significant correlation of -0.30 emerged among these variables. The mean Spatial Hearing Questionnaire score for females was 60.0 (SE=2.3, SD=20.3) and for males, the mean Spatial Hearing Questionnaire score was 48.6 (SE=2.7, SD=21.8). This difference was also not statistically significant ($t(140) = 3.23, p > 0.05$). Because there was no influence of age or gender in the data, all data was pooled together to complete the final analyses.

Factor Analysis

Factor analysis is often used in questionnaire development to determine the existence of relationships between items in a questionnaire and any clustering effects among them. The general principle of factor analysis is that the items should load on certain underlying factors that are highly correlated to the items. The amount of variance accounted for by each factor is determined in factor analysis, with the first factor accounting for the highest possible variance

(and therefore, producing the best relationship among the items) and the remaining factors representing the maximum amount of variance not accounted for by the first factor. The extracted factors have an assigned eigenvalue (or the amount of variance in the items accounted for by each component) and factors with eigenvalues greater than 1.0 are often retained (Kaiser 1960). Various methods of factor rotation exist, including varimax rotation (spreads the variation more evenly across the factors), oblique rotation (produces correlated factors), and orthogonal rotation (produces uncorrelated factors). In addition, the proportion of common variance in an item, called the communality is also estimated by factor analysis. High communality values (>0.50) are desired and indicate that the items are highly influenced by the factors (Flamme 2001).

To determine if factor analysis should be used to interpret data from the Spatial Hearing Questionnaire, the Kaiser-Meyer-Olkin (SPSS, v. 15.0) measure of statistic adequacy was first completed. This test indicates the proportion of variance in the variables that might be caused by underlying factors. A ratio close to 1 indicates that factor analysis would be an appropriate test and a ratio close to 0 indicates that another form of analysis should be performed. The ratio for the Spatial Hearing Questionnaire was 0.88. The subjects-to-variables ratio is also an important indicator for the utility of factor analysis. For this study, the subject-to-variables ratio was 6:1 ($142 \text{ subjects} \div 24 \text{ items} = 5.9$). Previous research has recommended a ratio of at least 5:1 to use factor analysis (Osborne & Costello 2004). Based on a high Kaiser-Meyer-Olkin ratio and a reasonable subjects-to-variables ratio, factor analysis was used to analyze the data.

The factor structure of the Spatial Hearing Questionnaire was analyzed using the extraction method of principal component analysis (SPSS, v. 15.0). Table 2 lists the communality, or shared features, of each variable. Communality values ranged from 0.55 to 0.91. Three eigenvalues greater than 1 emerged from the 24 items. The eigenvalue, percent of variance, and cumulative percent of variance for the three factors are displayed in Table 3. The first factor explained 64.9% of the total variance (eigenvalue=15.6); the second factor explained 13.0% of the total variance (eigenvalue=3.1); and the third factor explained 5.3% of the total variance (eigenvalue=1.3).

To more easily interpret the data, factor loadings were rotated using Varimax rotation with Kaiser Normalization (this manipulation spreads the variation more evenly over the 3 components). Table 4 shows the rotated component matrix for the three components.

Analyzing the three separate factors, 12 items loaded on factor 1, 9 items loaded on factor 2, and 2 items loaded on factor 3. Further examination of these factors revealed that items from factor 1 (13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, and 24) related to the source localization subscale. For factor 2, the items (4, 5, 6, 7, 8, 9, 10, 11, and 12) related to understanding in noise with target and noise sources from the front, understanding in noise with spatially separate target and noise sources, and music listening in quiet subscales. Factor 3 included two items (1 and 2) that related to the subscales of understanding a man's voice and a woman's voice in quiet. One item, question 3, loaded equally on factors 2 and 3. Item 3 relates to understanding a child's voice in quiet. Because it loaded equally between factors 2 and 3, it was determined that the most logical placement for this item would be in factor 3, as factor 3 pertains to similar situations of understanding speech in quiet already represented by items 1 and 2. Overall, the results from factor analysis show that items concerning sound localization represent the majority of the questionnaire items which load on factor 1. More difficult speech understanding in noise and music listening situations are taken into account in factor 2 and easier listening situations in quiet are represented in factor 3.

Reliability

Reliability of the Spatial Hearing Questionnaire was assessed by performing Cronbach's α and the item-total correlation coefficients. A Cronbach's α of 0.98 was calculated for all 24 items. This high α indicates that there is good internal consistency reliability for the questionnaire. Cronbach's α was also computed for the three individual factors that emerged from factor analysis. For factor 1, $\alpha = 0.98$; for factor 2, $\alpha = 0.97$ and for factor 3, $\alpha = 0.76$, indicating good reliability for each of the three factors. Item-total correlations are given in Table 5. Item-total correlations ranged from 0.41 to 0.88, indicating that each of the 24 individual items correlated moderately well with the Spatial Hearing Questionnaire total score.

Construct Validity

Table 6 displays mean scores for unilateral and bilateral cochlear implant users for the Spatial Hearing Questionnaire, including the total, factor, and subscale scores, and mean scores for the six test measures. Independent sample *t*-tests were performed for each measure to determine significant differences among the two groups. Scores on the Spatial Hearing Questionnaire were significantly better for bilateral cochlear implant users compared to unilateral cochlear implant users for the total score and factor 1 score. Factor 2 yielded no significant difference between unilateral and bilateral cochlear implant users. Factor 3 also yielded no significant difference between the two groups; however, it is important to note that this factor resulted in the highest score of the three factors for unilateral and bilateral cochlear implant users.

Scores on the individual subscales were also calculated and are shown in Table 6. Scores were significantly different ($p > .05$) between unilateral and bilateral cochlear implant users for all subscales except understanding in noise with noise and target sources from the front and understanding in noise with spatially separate target and noise sources subscales. Additionally, subscale scores were highest for the understanding in quiet subscale and lowest for the source localization subscale for both unilateral and bilateral implant users.

For the six speech perception test measures, statistically significant results were found ($p > .05$) with bilateral cochlear implant users revealing better performance than unilateral cochlear implant users for the CNC monosyllabic word test, recognition of multiple jammers, everyday sounds localization, the SSQ total, and the SSQ subscale 2. Results from the HINT sentence test revealed no significant difference between unilateral and bilateral cochlear implant users.

Pearson correlation coefficients were computed to compare results for the six test measures to the Spatial Hearing Questionnaire (including total, factor 1, factor 2, and factor 3). The results for all subjects are displayed in Table 7. For CNC words in quiet, HINT sentences in quiet and the SSQ, the correlation to the Spatial Hearing Questionnaire was expected to be in a positive direction as a higher score is better for these tests. In comparison, for the recognition of multiple jammers and localization in quiet tests, the correlation to the Spatial Hearing Questionnaire was expected to be negative, as a lower score is better for the former two tests.

Table 7 also lists the number of subjects per condition and the probability that the correlation deviates from the null hypothesis. Shaded regions of the table highlight the portion of the Spatial Hearing Questionnaire (total or factor) that best match the speech perception, localization or SSQ test measure. For CNC word recognition in quiet, the correlations were significant when comparing CNC results to the Spatial Hearing Questionnaire total score, factor 1, factor 2 and factor 3. Comparing the HINT test results to the Spatial Hearing Questionnaire, only the correlations between factor 1 and factor 3 were significant. For recognition of multiple jammers, the correlations to factor 2 and factor 3 were significant. For localization, the correlation to factor 1 was significant. Comparing the SSQ to the Spatial Hearing Questionnaire, the observed Pearson correlation coefficients were significant for the

total and all factor scores. Finally, comparing the spatial hearing subscale from the SSQ to the Spatial Hearing Questionnaire, correlations were significant for the total and all factor scores.

Figure 2 shows the scores on the Spatial Hearing Questionnaire before and after cochlear implantation. The average Spatial Hearing Questionnaire pre- and post-implant score (standard error and standard deviation in parentheses) for subjects with one cochlear implant ($n=13$) was 33.0% (3.5, 12.7) and 52.5% (6.3, 22.6), respectively, which resulted in a mean improvement of 19.5%. Comparing pre- to post-implant scores for unilateral cochlear implant users yielded a significant difference ($p > 0.01$, paired two-tailed t-test). For patients with bilateral implants ($n=13$), the mean pre- and post-implant score was 31.7% (5.4, 19.5) and 65.4.5% (4.6, 16.6), with a mean improvement of 33.8%. This also yielded a significant difference ($p > 0.000$, paired two-tailed t-test) when comparing pre- to post-implant scores for bilateral cochlear implant users. When unilateral and bilateral cochlear implant users were compared to one another, there was no significant difference on pre-implant scores ($p=0.83$), post-implant scores ($p=0.11$) and overall improvement in scores ($p=0.12$) from the pre-implant to post-implant condition using two-tailed independent t-tests. The non-significant results obtained for mean improvement in scores, as well as pre- and post-implant scores, for the unilateral and bilateral cochlear implant users are likely attributed to the small number of subjects and large standard deviation within each group.

Discussion

The results of this study indicate that the Spatial Hearing Questionnaire is a reliable and valid questionnaire. Internal consistency reliability (Cronbach's $\alpha = 0.98$) is high. Additionally, correlations between the Spatial Hearing Questionnaire and other test measures were significant and expected differences between unilateral and bilateral cochlear implants were evident, indicating that construct validity was adequate. A preliminary factor analysis revealed that three general factors underlie patient responses. *Factor 1* related to the source localization subscale. *Factor 2* related to subscales focused on speech understanding in noise with coincident target and noise sources, speech understanding in noise with spatially separate target and noise sources, and music listening in quiet. *Factor 3* related to understanding speech in quiet subscales, including the subscales for male, female, and children's voices. We suggest a further factor analysis is warranted and should include more subjects, and subjects with unilateral and bilateral hearing aids and cochlear implants, and combinations thereof.

The questionnaire was designed such that subscales can be compared with one another to assess different aspects of spatial hearing. For example, one could compare understanding speech in quiet from the front (subscale 6) to understanding speech in noise from the front (subscale 7); or one could contrast source localization (subscale 5) to understanding speech in spatially separate noise (subscale 8).

Significant improvements in Spatial Hearing Questionnaire scores from pre- to post-implant were noted for both unilateral and bilateral cochlear implant subject groups. Greater improvement on the Spatial Hearing Questionnaire was seen for subjects with bilateral cochlear implants compared to subjects with a unilateral cochlear implant. Additionally, scores on the Spatial Hearing Questionnaire, including the total score, factor 1, and six of the eight subscales were significantly higher for bilateral cochlear implant users compared to subjects with a unilateral cochlear implant. Mean scores for all test measures (i.e., CNC word recognition in quiet, recognition of multiple jammers, everyday sounds localization, and the SSQ) except the HINT in quiet were significantly higher for subjects with bilateral cochlear implants compared to subjects with a unilateral cochlear implant. It should be noted that the unilateral and bilateral cochlear implant users were not matched for specific characteristics such as degree of deafness, age at implantation, etc. Therefore, comparisons of speech recognition performance can not

be assumed to be solely due to one versus two. Despite this difference, results from the present study reveal that the Spatial Hearing Questionnaire is a sensitive test in that it was able to detect a difference between unilateral and bilateral cochlear implant users in their subjective spatial hearing abilities.

In the present study, evaluation of the Spatial Hearing Questionnaire was limited to cochlear implant users. Future studies should investigate the utility of this questionnaire in other patient populations such as unilateral and bilateral hearing aid users, and users of a cochlear implant and hearing aid in opposite ears.

Lastly, with only 24 items, the Spatial Hearing Questionnaire is relatively quick to administer to patients. The total Spatial Hearing Questionnaire score gives the clinician an indication of how the patient perceives their spatial hearing abilities or disabilities and subscale scores provide details on how the patient performs in specific situations. The ease of scoring (100 point scale) and relative brevity of the Spatial Hearing Questionnaire makes it likely to be a valuable, efficient tool for clinicians and hearing scientists.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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References

- Colburn, HS.; Zurek, PM.; Durlach, NI. Binaural directional hearing-impairments and aids. In: Yost, WA.; Gourevitch, G., editors. Directional hearing. New York: Springer-Verlag; 1987. p. 261-278.
- Cox RM, Alexander GC. The abbreviated profile of hearing aid benefit. *Ear and Hearing* 1995;16:176–186. [PubMed: 7789669]
- Cox RM, Alexander GC. Measuring satisfaction with amplification in daily life: The SADL scale. *Ear and Hearing* 1999;20(4):306–334. [PubMed: 10466567]
- Cox RM, Alexander GC. Validation of the SADL questionnaire. *Ear and Hearing* 2001;22(2):151–160. [PubMed: 11324844]
- Dunn CC, Tyler RS, Witt SA. Benefit of wearing a hearing aid on the unimplanted ear in adult users of a cochlear implant. *Journal of Speech, Language, and Hearing Research* 2005;48:668–680.
- Firszt JB, Holden LK, Skinner MW, et al. Recognition of speech presented at soft to loud levels by adult cochlear implant recipients of three cochlear implant systems. *Ear & Hearing* 2004;25(4):375–387. [PubMed: 15292777]
- Flamme GA. Examination of the validity of auditory traits and tests. *Trends in Amplification* 2001;5(3): 111–138.
- Gatehouse S. Glasgow hearing aid benefit profile: Derivation and validation of a client-centered outcome measure for hearing aid services. *Journal of the American Academy of Audiology* 1999;10:80–103.
- Gatehouse S, Noble W. The speech, spatial and qualities of hearing scale (SSQ). *International Journal of Audiology* 2004;43:85–99. [PubMed: 15035561]
- Gifford RH, Shallop JK, Peterson AM. Speech recognition materials and ceiling effects: Considerations for cochlear implant programs. *Audiology and Neuro-otology* 2008;13:193–205. [PubMed: 18212519]

- Hawley ML, Litovsky RL, Colburn HS. Speech intelligibility and localization in a multi-source environment. *Journal of the Acoustical Society of America* 1999;105:3436–3448. [PubMed: 10380667]
- Kaiser HF. The application of electronic computers to factor analysis. *Educational and Psychological Measurement* 1960;20:141–151.
- Laszig R, Aschendorff A, Stecker M, et al. Benefits of bilateral electrical stimulation with the Nucleus cochlear implant in adults: 6-month postoperative results. *Otology and Neurotology* 2004;25:958–968. [PubMed: 15547426]
- Litovsky R, Parkinson A, Arcaroli J, et al. Simultaneous bilateral cochlear implantation in adults: A multicenter clinical study. *Ear and Hearing* 2006;27(6):714–731. [PubMed: 17086081]
- MacKeith NW, Coles RR. Binaural advantages in hearing of speech. *Journal of Laryngology and Otology* 1971;85(3):213–232. [PubMed: 5550604]
- Nilsson M, Soli SD, Sullivan JA. Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. *Journal of the Acoustical Society of America* 1994;95(2):1085–1099. [PubMed: 8132902]
- Noble W. Self-assessment of hearing and related functions. London: Whurr Publishers Ltd; 1998.
- Noble W. Bilateral hearing aids: A review of self-reports of benefit in comparison with unilateral fitting. *International Journal of Audiology* 2006;45(7):63–71.
- Noble W, Gatehouse S. Interaural asymmetry of hearing loss, Speech, Spatial and Qualities of Hearing Scale (SSQ) disabilities, and handicap. *International Journal of Audiology* 2004;43:100–114. [PubMed: 15035562]
- Noble W, Gatehouse S. Effects of bilateral versus unilateral hearing aid fitting on abilities measured by Speech, Spatial and Qualities of Hearing Scale (SSQ). *International Journal of Audiology* 2006;45:172–181. [PubMed: 16579492]
- Noble W, Ter-Horst K, Byrne D. Disabilities and handicaps associated with impaired auditory localization. *Journal of the American Academy of Audiology* 1995;6(2):129–140. [PubMed: 7772782]
- Nopp P, Schleich P, D’Haease P. Sound localization in bilateral users of Med-El COMBI 40/40+ cochlear implants. *Ear and Hearing* 2004;25(3):205–214. [PubMed: 15179112]
- Osborne, JW.; Costello, AB. Sample size and subject to item ratio in principal components analysis. *Practical Assessment, Research & Evaluation*. 2004. Retrieved June 4, 2008 from <http://PAREonline.net/getvn.asp?v=9&n=11>
- Peissig J, Kollmeier B. Directivity of binaural noise reduction in spatial multiple noise-source arrangements for normal hearing and impaired listeners. *Journal of the Acoustic Society of America* 1997;101(3):1660–1670.
- Ruscetta MN, Palmer CV, Durrant JD, et al. Validity, internal consistency, and test/retest reliability of a localization disabilities and handicaps questionnaire. *Journal of the American Academy of Audiology* 2005;16(8):585–595. [PubMed: 16295245]
- Tillman, TW.; Carhart, R. An expanded test for speech discrimination utilizing CNC monosyllabic words. Northwestern University Auditory Test No. 6 Technical Report No. SAM-TR-66–55; 1966. p. 1-12.
- Tyler RS, Gantz BJ, Rubinstein JT, et al. Three-month results with bilateral cochlear implants. *Ear and Hearing* 2002;23:80S–89S. [PubMed: 11883771]
- Tyler, RS.; Dunn, CC.; Witt, SA., et al. Soundfield hearing for patients with cochlear implants and hearing aids. In: Cooper, HR.; Craddock, LC., editors. *Cochlear implants, A practical guide*. London and Philadelphia: Whurr Publishers; 2006a. p. 338-365.
- Tyler RS, Noble W, Dunn C, et al. Some benefits and limitations of binaural cochlear implants and our ability to measure them. *International Journal of Audiology* 2006b;45 (Supplement 1):S113–S119. [PubMed: 16938783]
- Tyler RS, Dunn CC, Witt SA, et al. Speech perception and localization with adults with bilateral sequential cochlear implants. *Ear and Hearing* 2007;28(2):86S–90S. [PubMed: 17496655]
- Van Hoesel RJM, Tyler RS. Speech perception, localization and lateralization with bilateral cochlear implants. *Journal of the Acoustic Society of America* 2003;113(3):1617–1630.
- Ventry IM, Weinstein BE. The hearing handicap inventory for the elderly: A new tool. *Ear and Hearing* 1982;3:128–134. [PubMed: 7095321]

- Vershuur CA, Lutman ME, Ramsden R, et al. Auditory localization abilities in bilateral cochlear implant recipients. *Otology and Neurology* 2005;26:965–971.
- Walden BE, Demorest ME, Hepler EL. Self-report approach to assessing benefit derived from amplification. *Journal of Speech and Hearing Research* 1984;27:49–56. [PubMed: 6717006]
- Zurek, PM. Binaural advantages and directional effects in speech intelligibility. In: Studebaker, GA.; Hochberg, I., editors. *Acoustical factors affecting hearing aid performance*. Vol. 2. Boston: Allyn and Bacon; 1993.

Figure 1.
The age distribution for female and male subjects.

Figure 2. Mean Spatial Hearing Questionnaire scores for unilateral and bilateral cochlear implant users measured before and after cochlear implantation. Significant differences are marked by the brackets. Note. ** $p < .01$ level.

Table 1

Implant type for all subjects (n=142). The implant type for unilateral implant subjects is presented in the second column. Columns three, four and five summarize the type of devices used by bilateral cochlear implant subjects. Bilateral simultaneously implanted subjects are included in column three. Data for sequentially implanted subjects is listed in the right most portion of the table, in columns four and five.

Implant type	Unilateral cochlear implant subjects (# with device)	Bilateral cochlear implant subjects		
		Simultaneous (# with device)	Sequential	
			Implant type	(# with device)
Clarion HiFocus CII	10	9	Ineraid/Clarion HiFocus CII	1
Clarion HiRes 90K with Helix	3	1	Ineraid/Nucleus CI24M	1
Clarion HiFocus 1.2	8	1	Ineraid/Clarion HiRes 90K	1
Clarion HiFocus II	1		Clarion Standard 1.0/Clarion HiRes 90K	2
Clarion Radial Bipolar/Standard 1.0	12		Nucleus CI24R/Nucleus CI24M	1
Clarion HiRes 90K	8	8		
Nucleus CI24R	17	4		
Nucleus CI24M	18	9		
Nucleus CI22	11			
Nucleus CI 24RE(CA)	6	3		
Nucleus CI 24R(CA)	5	1		
Ineraid	1			
<i>Total</i>	<i>N=100</i>	<i>N=36</i>		<i>N=6</i>

Table 2

Communality values for each item from the questionnaire (n=142).

Item	Communality
1	0.75
2	0.83
3	0.70
4	0.55
5	0.87
6	0.87
7	0.86
8	0.82
9	0.86
10	0.80
11	0.81
12	0.83
13	0.91
14	0.91
15	0.89
16	0.87
17	0.91
18	0.91
19	0.90
20	0.86
21	0.80
22	0.89
23	0.76
24	0.83

Table 3

Eigenvalues, percentage of variance, and cumulative percentage of variance represented by the three factors (n=142).

Factor	Eigenvalue	% of Variance	Cumulative % of Variance
1	15.6	64.9	64.9
2	3.1	13.0	77.9
3	1.3	5.3	83.2

Table 4

Rotated component matrix for the three factors. Variables are grouped according to the factors (in bold) and are listed numerically by item number (n=142).

Item	Factor		
	1	2	3
13	0.91	0.24	0.16
14	0.91	0.23	0.18
15	0.86	0.32	0.21
16	0.87	0.32	0.15
17	0.90	0.29	0.08
18	0.89	0.31	0.13
19	0.85	0.40	0.12
20	0.87	0.32	0.02
21	0.85	0.29	0.05
22	0.90	0.29	0.08
23	0.76	0.40	0.13
24	0.82	0.36	0.13
4	0.27	0.67	0.16
5	0.37	0.79	0.34
6	0.36	0.79	0.35
7	0.45	0.78	0.24
8	0.32	0.84	0.02
9	0.31	0.83	0.27
10	0.27	0.82	0.26
11	0.38	0.80	0.19
12	0.29	0.86	0.03
1	0.12	0.21	0.83
2	0.05	0.30	0.86
3	0.27	0.56	0.55

Table 5

Item-total correlation coefficients for each item on the Spatial Hearing Questionnaire (n=142).

Item	Item-Total Correlation
1	0.41
2	0.42
3	0.66
4	0.67
5	0.85
6	0.84
7	0.85
8	0.77
9	0.82
10	0.75
11	0.81
12	0.76
13	0.83
14	0.83
15	0.86
16	0.85
17	0.84
18	0.85
19	0.88
20	0.83
21	0.79
22	0.82
23	0.83
24	0.84

Table 6

Mean scores and *t*-test results for the Spatial Hearing Questionnaire total score, the factor scores, the 8 subscales, and the 6 test measures. The *n* for each group is listed in the column to the right next to the mean scores.

Test Measures	Unilateral CI Mean (SE, SD)	n	Bilateral CI Mean (SE, SD)	n	<i>t</i>	<i>df</i>	<i>p</i>
Total	51.3 (2.1, 21.3)	100	62.7 (3.2, 20.5)	42	-3.0	80	.00**
Factor 1	38.6 (2.7, 26.5)	100	56.3 (4.1, 26.3)	42	-3.6	140	.00**
Factor 2	53.7 (2.6, 26.0)	100	61.3 (3.4, 22.1)	42	-1.6	140	.11
Factor 3	83.0 (1.5, 14.9)	100	87.6 (2.0, 12.7)	42	-1.7	140	.09
Male	58.8 (2.0, 19.8)	100	68.2 (3.2, 20.5)	42	-2.6	140	.01**
Female	58.2 (2.1, 20.7)	100	68.6 (2.8, 18.4)	42	-2.8	140	.01**
Child	48.2 (2.4, 23.5)	100	58.8 (3.5, 23.0)	42	-2.5	140	.02*
Music	44.5 (2.6, 25.7)	100	57.2 (3.8, 24.7)	42	-2.7	140	.01**
Quiet	78.0 (1.7, 16.9)	100	84.1 (2.2, 14.3)	42	-2.1	140	.04*
Source Localization	38.6 (2.7, 26.5)	100	56.3 (4.1, 26.3)	42	-3.6	140	.00**
Understanding in Noise-Front	52.3 (2.7, 26.7)	100	60.4 (3.5, 22.4)	42	-1.7	140	.09
Understanding in Noise-Spatially	53.2 (2.7, 26.6)	100	58.9 (3.5, 22.8)	42	-1.2	140	.22
CNC (%)	50.0 (2.6, 24.3)	89	65.0 (3.8, 22.8)	35	3.2	123	.00**
HINT in Quiet (%)	79.4 (2.7, 26.5)	95	89.3 (3.3, 16.7)	26	1.8	119	.07
Multiple Jammer (S/N in dB)	0.69 (0.9, 4.6)	28	-2.8 (1.0, 4.4)	20	-2.6	46	.01**
Localization (RMS degrees error)	44.6 (1.1, 6.1)	29	19.5 (1.8, 10.5)	34	-11.3	61	.00**
SSQ							
Total	4.9 (0.2, 1.9)	99	5.9 (0.3, 1.8)	40	2.9	137	.00**
Subscale 2	4.1 (0.2, 2.1)	99	5.7 (0.3, 2.1)	40	4.0	137	.00**

* Note. $p < .05$.

** $p < .01$.

Table 7

Pearson correlation coefficients among scores on the Spatial Hearing Questionnaire and the six test measures. Shaded regions highlight the portion of the Spatial Hearing Questionnaire (total versus one of the three factors) that best matches the test measure.

	CNC Words in Quiet	HINT in Quiet	Recognition of Multiple Jammers	Localization	SSQ	
					Total	Spatial Hearing Subscale
Total	0.30** n=125 p=0.001	0.16 n=121 p=0.074	-0.24 n=48 p=0.107	-0.23 n=63 p=0.069	0.79** n=139 p<0.001	0.75** n=139 p<0.001
Factor 1 (Directionality)	0.24** n=124 p=0.006	0.19* n=121 p=0.035	-0.11 n=48 p=0.462	-0.34** n=63 p=0.006	0.78** n=139 p<0.001	0.84** n=139 p<0.001
Factor 2 (Speech in Noise, Music)	0.29** n=125 p=0.001	0.17 n=121 p=0.056	-0.29* n=48 p=0.047	-0.01 n=63 p=0.919	0.70** n=139 p<0.001	0.56** n=139 p<0.001
Factor 3 (Speech in Quiet)	0.32** n=125 p<0.001	0.21* n=121 p=0.022	-0.39** n=48 p=0.007	-0.042 n=63 p=0.741	0.60** n=139 p<0.001	0.46** n=139 p<0.001

* Note. $p < .05$.

**
p < .01.