Validation of the Spatial Hearing Questionnaire

Richard S. Tyler, Ann E. Perreau, and Haihong Ji

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 with 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 to 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 questionnaire was completed to evaluate validity of the questionnaire. Psychometric tests were performed 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 Speech, Spatial, and Other Qualities, 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 that represents the subscale related to source localization. Mean scores on the Spatial Hearing Questionnaire were higher for subjects with bilateral cochlear implants than for 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 that 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.

(Ear & Hearing 2009;30;466–474)

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 (MacKeith & Coles 1971; Colburn et al. 1987; Zurek 1993; Peissig & Kollmeier 1997; Vershuur et al. 2005; Tyler et al. 2006a,b). Questionnaires have been developed for this purpose to report more specifically the situations faced by listeners with hearing impairment (Ventry & Weinstein 1982; Walden et al. 1984; Gatehouse 1999; Cox & Alexander 1995, 1999, 2001; Noble 1998, 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 use hearing from two ears. Spatial hearing is characterized by hearing in the sound field (but not necessary with two ears). Binaural hearing is hearing that involves both ears and is typically thought to 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 et al. (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 et al. 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 because 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 sections I and II. Previously reported results by Flamme (2001) agreed well with those reported in this study by Ruscetta et al. for section I of the questionnaire. Finally, subjects completed the questionnaire a second time, 3 weeks after the first administration, and test-retest reliability was highly significant.

Based on the work of Noble et al., the Speech, Spatial, and Qualities of Hearing Scale (SSQ) (Gatehouse & Noble 2004; Noble & Gatehouse 2004, 2006) was developed to study further the relationship of disability and handicap to hearing experience across a wide variety of listening domains. The

Department of Otolaryngology–Head and Neck Surgery, The University of Iowa, Iowa City, Iowa.

0196/0202/09/3004-0466/0 • Ear & Hearing • Copyright © 2009 by Lippincott Williams & Wilkins • Printed in the U.S.A.

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 and fifty-three subjects using hearing aids were evaluated with the SSQ (Gatehouse & Noble 2004; Noble & 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 three 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 into three 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 hear 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 well-being 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 (Van Hoesel & Tyler 2003; Laszig et al. 2004; Nopp et al. 2004; Verschuur et al. 2005; Litovsky et al. 2006; Tyler et al. 2002, 2007). The purpose of the present study is to describe the sensitivity and psychometric property of the Spatial Hearing Questionnaire, show its validity and reliability, and perform a preliminary analysis of its factor structure.

MATERIALS AND METHODS

The Spatial Hearing Questionnaire consists of 24 questions (see Appendix). Patients score each question independently on a scale from 0 to 100, where 0 indicates that the situation is very difficult and 100 indicates that the situation is very easy. 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 to 24)
6. Understanding speech in quiet (items 1 to 4)
7. Understanding speech in noise with target and noise sources from the front (items 5 to 8)
8. Understanding speech in noise with spatially separate target and noise sources (items 9 to 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, 77 women and 65 men, participated in this study. 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 postoperatively. 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 dropouts, 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 with 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 & 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 of 142 subjects 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

TABLE 1. Implant type for all subjects (n = 142)

Implant type	Unilateral cochlear implant subjects (No. with device)	Bilateral cochlear implant subjects: Simultaneous (No. with device)	Bilateral cochlear implant subjects: Sequential — Implant type	Sequential (No. 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			
Total	n = 100	n = 36		n = 6

The implant type for unilateral implant subjects is presented in the second column. Columns 3, 4, and 5 summarize the type of devices used by bilateral cochlear implant subjects. Bilateral simultaneously implanted subjects are included in column 3. Data for sequentially implanted subjects are listed in the rightmost portion of the table, in columns 4 and 5.

(Nilsson et al. 1994). Although the HINT sentence was originally developed to be presented with background noise, this test has been implemented in the clinical and research protocols of cochlear implant centers to assess sentence recognition abilities in quiet (Firszt et al. 2004; Gifford et al. 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 et al. (1999) and is referred to as the Recognition of Multiple Jammers (see Tyler et al. 2006b for more details). This test used an eight-loudspeaker array spanning 108° in front of the subject. An adaptive spondee word was presented from one of two loudspeakers (placed either ±8° 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 and −38° azimuth or at −54 and +38° 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 on the Recognition of 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) 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 et al. 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 to 20°) would represent good localization abilities. Chance performance is approximately 40° RMS error. Sixty-three of the total 142 subjects 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 & 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 preoperatively, 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 readministered to all 26 subjects. The mean sentence recognition score for the 26 subjects before implantation was 17.2%

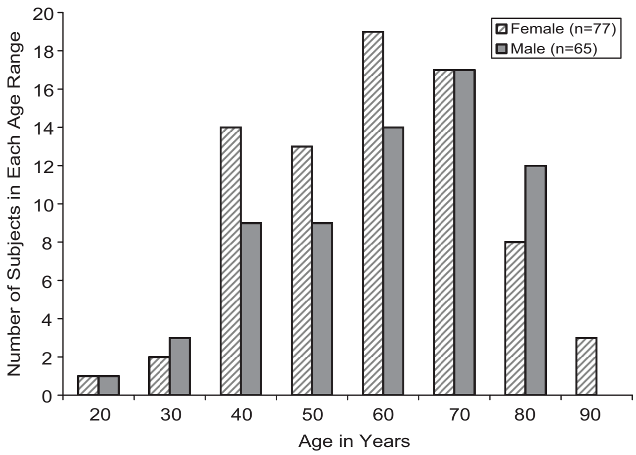

Fig. 1. Age distribution for female and male subjects.

(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 Fig. 1). A Pearson correlation coefficient was calculated to compare the age of the subjects with their Spatial Hearing Questionnaire scores. A nonsignificant correlation of −0.30 emerged among these variables. The mean Spatial Hearing Questionnaire score was 60.0 (SE = 2.3, SD = 20.3) for women and 48.6 (SE = 2.7, SD = 21.8) for men. 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 were pooled together to complete the final analyses.

Factor Analysis

Factor analysis is often used in questionnaire development to determine the existence of relationships among 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 with 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 estimated by factor analysis. High communality values (> 0.50) are desired and indicate that the items are highly influenced by the factors (Flamme 2001).

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

To determine whether 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 subjects/24 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 interpret the data more easily, 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.

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

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 revealed that items from factor 1 (13 through 24) related to the source localization subscale. For factor 2, the items (4 through 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, because 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 that 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.

TABLE 4. Rotated component matrix for the three factors

	Factor		
Item	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**

*Variables are grouped according to the factors (in bold) and are listed numerically by item number (*n* = 142).*

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

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 between the two groups. Scores on the Spatial Hearing Questionnaire were significantly better for bilateral cochlear implant users compared with 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

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

Test measures	Unilateral CI Mean (SE, SD)	*n*	Bilateral CI Mean (SE, SD)	*n*	*T*	df	*p*
Total	51.3 (2.1, 21.3)	100	62.7 (3.2, 20.5)	42	−3.0	80	0.00*
Factor 1	38.6 (2.7, 26.5)	100	56.3 (4.1, 26.3)	42	−3.6	140	0.00*
Factor 2	53.7 (2.6, 26.0)	100	61.3 (3.4, 22.1)	42	−1.6	140	0.11
Factor 3	83.0 (1.5, 14.9)	100	87.6 (2.0, 12.7)	42	−1.7	140	0.09
Male	58.8 (2.0, 19.8)	100	68.2 (3.2, 20.5)	42	−2.6	140	0.01*
Female	58.2 (2.1, 20.7)	100	68.6 (2.8, 18.4)	42	−2.8	140	0.01*
Child	48.2 (2.4, 23.5)	100	58.8 (3.5, 23.0)	42	−2.5	140	0.02†
Music	44.5 (2.6, 25.7)	100	57.2 (3.8, 24.7)	42	−2.7	140	0.01*
Quiet	78.0 (1.7, 16.9)	100	84.1 (2.2, 14.3)	42	−2.1	140	0.04†
Source localization	38.6 (2.7, 26.5)	100	56.3 (4.1, 26.3)	42	−3.6	140	0.00*
Understanding in noise–front	52.3 (2.7, 26.7)	100	60.4 (3.5, 22.4)	42	−1.7	140	0.09
Understanding in noise–spatially	53.2 (2.7, 26.6)	100	58.9 (3.5, 22.8)	42	−1.2	140	0.22
CNC (%)	50.0 (2.6, 24.3)	89	65.0 (3.8, 22.8)	35	3.2	123	0.00*
HINT in quiet (%)	79.4 (2.7, 26.5)	95	89.3 (3.3, 16.7)	26	1.8	119	0.07
Multiple jammer (S/N in dB)	0.69 (0.9, 4.6)	28	−2.8 (1.0, 4.4)	20	−2.6	46	0.01*
Localization (RMS degrees error)	44.6 (1.1, 6.1)	29	19.5 (1.8, 10.5)	34	−11.3	61	0.00*
SSQ							
Total	4.9 (0.2, 1.9)	99	5.9 (0.3, 1.8)	40	2.9	137	0.00*
Subscale 2	4.1 (0.2, 2.1)	99	5.7 (0.3, 2.1)	40	4.0	137	0.00*

CI indicates cochlear implant. The n for each group is listed in the column to the right next to the mean scores.
** $p < 0.01$.*
† $p < 0.05$.

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 ($p > 0.05$) 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 ($p > 0.05$) 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 in quiet revealed no significant difference between unilateral and bilateral cochlear implant users.

Pearson correlation coefficients were computed to compare results for the six test measures with the Spatial Hearing Questionnaire (including total and factors 1, 2, and 3). The results for all subjects are listed in Table 7. For CNC words in quiet, HINT sentences in quiet, and the SSQ, the correlation with the Spatial Hearing Questionnaire was expected to be in a positive direction because a higher score is better for these

TABLE 7. Pearson correlation coefficients among scores on the Spatial Hearing Questionnaire and the six test measures

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

Bolded regions highlight the portion of the Spatial Hearing Questionnaire (total vs. one of the three factors) that best matches the test measure.
** $p < .05$.*
*** $p < .01$.*

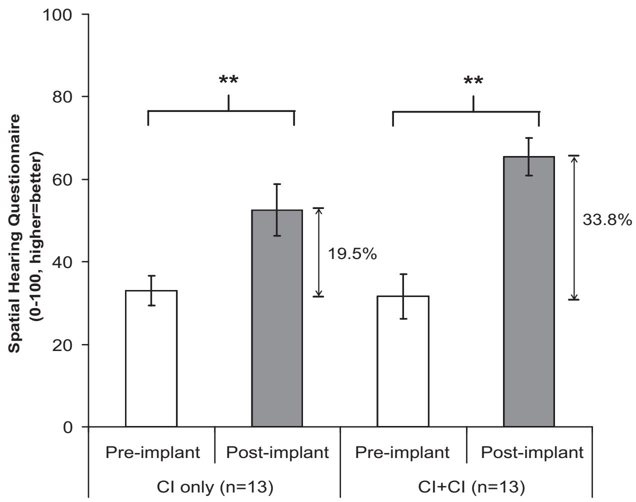

Fig. 2. Mean Spatial Hearing Questionnaire scores for unilateral and bilateral cochlear implant (CI) users measured before and after cochlear implantation. Significant differences are marked by brackets. $^{**}p < 0.01$ level.

tests. In comparison, for the recognition of multiple jammers and localization in quiet tests, the correlation with the Spatial Hearing Questionnaire was expected to be negative, because 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. Bolded 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 with the Spatial Hearing Questionnaire total score and factors 1, 2, and 3. Comparing the HINT results with the Spatial Hearing Questionnaire, only the correlations between factors 1 and 3 were significant. For recognition of multiple jammers, the correlations with factors 2 and 3 were significant. For localization, the correlation with factor 1 was significant. Comparing the SSQ with 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 with 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 postimplant scores (SE and SD in parentheses) for subjects with one cochlear implant ($N = 13$) were 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- with postimplant 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 postimplant scores were 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- with postimplant scores for bilateral cochlear implant users. When unilateral and bilateral cochlear implant users were compared with one another, there was no significant difference on preimplant scores ($p = 0.83$), postimplant scores ($p = 0.11$), and overall improvement in scores ($p = 0.12$) from the preimplant to postimplant condition using two-tailed independent t-tests. The nonsignificant results obtained for mean improvement in scores, as well as pre- and postimplant scores, for the unilateral and bilateral cochlear implant users are likely attributed to the small number of subjects and large SD 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 that 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 so 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) with 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 postimplant 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 with 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 with 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 with 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 and age at implantation. Therefore, comparisons of speech recognition performance cannot be assumed to be solely the result of one versus two implants. 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 this 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.

Finally, 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 his or her 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 make it likely to be a valuable, efficient tool for clinicians and hearing scientists.

ACKNOWLEDGMENTS

The authors thank Shelley Witt and Camille Dunn for their dedication to this project and for editing this manuscript.

This research was supported in part by research grant 5 P50 DC00242 from the National Institutes on Deafness and Other Communication Disorders, National Institutes of Health; grant M01-RR-59 from the General Clinical Research Centers Program, Division of Research Resources, National Institutes of Health; the Lions Clubs International Foundation; and the Iowa Lions Foundation.

Address for correspondence: Ann E. Perreau, The University of Iowa, Department of Otolaryngology–Head & Neck Surgery, 200 Hawkins Dr. 21016 PFP, Iowa City, Iowa 52242. E-mail: ann-perreau@uiowa.edu.

Received March 27, 2008; accepted February 21, 2009.

APPENDIX

The Spatial Hearing Questionnaire

NAME__________________HOSP. #___________
DATE__________________TEST SESSION # _______________

Please respond to each question with a number from 0-100. Number 0 means the situation would be very difficult. Number 100 means the situation would be very easy.

0….Very Difficult **100….Very Easy**

1.	A **man** talking to you is standing in front of you. It is a **very quiet room**. How well can you understand **him**?	
2.	A **woman** talking to you is standing in front of you. It is a **very quiet room**. How well can you understand **her**?	
3.	A **child** talking to you is standing in front of you. It is a **very quiet room**. How well can you understand the **child**?	
4.	You are listening to **music** that is comfortably loud coming from in front of you. It is a **very quiet room**. How easy or difficult is it to hear the **music** clearly?	
5.	A **man** talking to you is standing in front of you. There is a loud fan **directly behind him**. How well can you understand **him**?	
6.	A **woman** talking to you is standing in front of you. There is a loud fan **directly behind her**. How well can you understand **her**?	
7.	A **child** talking to you is standing in front of you. There is a loud fan **directly behind the child**. How well can you understand the **child**?	
8.	**You** are listening to comfortably loud **music** coming from **in front** of you. There is also a loud fan **in front** of you. How easy or difficult is it to hear the **music** clearly?	
9.	A **man** talking to you is standing in front of you. There is a loud fan **off to one side**. How well can you understand **him**?	

0….Very Difficult **100….Very Easy**

10.	A **woman** talking to you is standing **in front** of you. There is a loud fan **off to one side**. How well can you understand **her**?	
11.	A **child** talking to you is standing **in front** of you. There is a loud fan **off to one side**. How well can you understand the **child**?	
12.	You are listening to comfortably loud **music** coming from **in front** of you. There is also a loud fan **off to one side**. How easy or difficult is it to hear the **music** clearly?	
13.	How well are you able to **determine the location** of a **man's** voice when you **cannot see** him?	
14.	How well are you able to **determine the location** of a **woman's** voice when you **cannot see** her?	
15.	How well are you able to **determine the location** of a **child's** voice when you **cannot see** the child?	
16.	How well are you able to **determine the location** of a **music** source, say a radio, when you **cannot see** it?	
17.	How well are you able to **determine the location** of a **man's** voice when he is **behind you**?	
18.	How well are you able to **determine the location** of a **woman's** voice when she is **behind you**?	
19.	How well are you able to **determine the location** of a **child's** voice when the child is **behind you**?	
20.	How well are you able to **determine the location** of a **music** source, say a radio, when it is **behind you**?	
21.	How well are you able to **determine the location** of a **flying airplane** when you **cannot see** it?	
22.	You hear a **car off in the distance**, but you cannot see it. How accurately can you tell **where it is coming from**?	
23.	If you were to stand **beside a road** and close your eyes, how well could you tell what **direction a car was going** as it passed by?	
24.	You are in a room in a house and hear a loud **sound**. How easily can you tell **how far away** the **sound** was?	

REFERENCES

Colburn, H. S., Zurek, P. M., Durlach, N. I. (1987). Binaural directional hearing-impairments and aids. In W.A. Yost & G. Gourevitch (Eds). *Directional Hearing* (pp, 261–278). New York: Springer-Verlag.

Cox, R. M., & Alexander, G. C. (1995). The abbreviated profile of hearing aid benefit. *Ear Hear*, *16*, 176–186.

Cox, R. M., & Alexander, G. C. (1999). Measuring satisfaction with amplification in daily life: The SADL scale. *Ear Hear*, *20*, 306–334.

Cox, R. M., & Alexander, G. C. (2001). Validation of the SADL questionnaire. *Ear Hear*, *22*, 151–160.

Dunn, C. C., Tyler, R. S., Witt, S. A. (2005). Benefit of wearing a hearing aid on the unimplanted ear in adult users of a cochlear implant. *J Speech Lang Hear Res*, *48*, 668–680.

Firszt, J. B., Holden, L. K., Skinner, M. W., et al. (2004). Recognition of speech presented at soft to loud levels by adult cochlear implant recipients of three cochlear implant systems. *Ear Hear*, *25*, 375–387.

Flamme, G. A. (2001). Examination of the validity of auditory traits and tests. *Trends Amplif*, *5*, 111–138.

Gatehouse, S. (1999). Glasgow hearing aid benefit profile: Derivation and validation of a client-centered outcome measure for hearing aid services. *J Am Acad Audiol*, *10*, 80–103.

Gatehouse, S., & Noble, W. (2004). The speech, spatial and qualities of hearing scale (SSQ). *Int J Audiol*, *43*, 85–99.

Gifford, R. H., Shallop, J. K., Peterson, A. M. (2008). Speech recognition materials and ceiling effects: Considerations for cochlear implant programs. *Audiol Neurootol*, *13*, 193–205.

Hawley, M.L., Litovsky, R. L., Colburn, H. S. (1999). Speech intelligibility and localization in a multi-source environment. *J Acoust Soc Am*, *105*, 3436–3448.

Kaiser, H. F. (1960). The application of electronic computers to factor analysis. *Educ Psychol Measure*, *20*, 141–151.

Laszig, R., Aschendorff, A., Stecker, M., et al. (2004). Benefits of bilateral electrical stimulation with the Nucleus cochlear implant in adults: 6-month postoperative results. *Otol Neurotol*, *25*, 958–968.

Litovsky, R., Parkinson, A., Arcaroli, J., et al. (2006). Simultaneous bilateral cochlear implantation in adults: A multicenter clinical study. *Ear Hear*, *27*, 714–731.

MacKeith, N. W., & Coles, R. R. (1971). Binaural advantages in hearing of speech. *J Laryngol Otol*, *85*, 213–232.

Nilsson, M., Soli, S. D., Sullivan, J. A. (1994). Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. *J Acoust Soc Am*, *95*, 1085–1099.

Noble, W. (1998). *Self-Assessment of Hearing and Related Functions*. London, UK: Whurr Publishers Ltd.

Noble, W. (2006). Bilateral hearing aids: A review of self-reports of benefit in comparison with unilateral fitting. *Int J Audiol*, *45*, 63–71.

Noble, W., & Gatehouse, S. (2004). Interaural asymmetry of hearing loss, Speech, Spatial and Qualities of Hearing Scale (SSQ) disabilities, and handicap. *Int J Audiol*, *43*, 100–114.

Noble, W., & Gatehouse, S. (2006). Effects of bilateral versus unilateral hearing aid fitting on abilities measured by Speech, Spatial and Qualities of Hearing Scale (SSQ). *Int J Audiol*, *45*, 172–181.

Noble, W., Ter-Horst, K., Byrne, D. (1995). Disabilities and handicaps associated with impaired auditory localization. *J Am Acad Audiol*, *6*, 129–140.

Nopp, P., Schleich, P., D'Haease, P. (2004). Sound localization in bilateral users of Med-El COMBI 40/40+ cochlear implants. *Ear Hear, 25*, 205–214.

Osborne, J. W., & Costello, A. B. (2004). Sample size and subject to item ratio in principal components analysis. *Pract Assess Res Evaluat, 9.* Retrieved June 4, 2008 from http://PAREonline.net/getvn.asp?v=9&n=11.

Peissig, J., & Kollmeier, B. (1997). Directivity of binaural noise reduction in spatial multiple noise-source arrangements for normal hearing and impaired listeners. *J Acoust Soc Am*, *101*, 1660–1670.

Ruscetta, M. N., Palmer, C. V., Durrant, J. D., et al. (2005). Validity, internal consistency, and test/retest reliability of a localization disabilities and handicaps questionnaire. *J Am Acad Audiol*, *16*, 585–595.

Tillman, T. W., & Carhart, R. (1966). An expanded test for speech discrimination utilizing CNC monosyllabic words. Northwestern University Auditory Test No. *6. Technical Report No SAM-TR-66-*, *55*, 1–12.

Tyler, R. S., Dunn, C. C., Witt, S. A., et al. (2006a). Soundfield hearing for patients with cochlear implants and hearing aids. In H. R. Cooper & L. C. Craddock (Eds). *Cochlear Implants: A Practical Guide* (pp, 338–365). London, UK: Whurr Publishers.

Tyler, R. S., Dunn, C. C., Witt, S. A., et al. (2007). Speech perception and localization with adults with bilateral sequential cochlear implants. *Ear Hear, 28*, 86S–90S.

Tyler, R. S., Gantz, B. J., Rubinstein, J. T., et al. (2002). Three-month results with bilateral cochlear implants. *Ear Hear, 23*, 80S–89S.

Tyler, R. S., Noble, W., Dunn, C., et al. (2006b). Some benefits and limitations of binaural cochlear implants and our ability to measure them. *Int J Audiol, 45* (Suppl 1), S113–S119.

Van Hoesel, R. J. M., & Tyler, R. S. (2003). Speech perception, localization and lateralization with bilateral cochlear implants. *J Acoust Soc Am*, *113*, 1617–1630.

Ventry, I. M., & Weinstein, B. E. (1982). The hearing handicap inventory for the elderly: A new tool. *Ear Hear*, *3*, 128–134.

Vershuur, C. A., Lutman, M. E., Ramsden, R., et al. (2005). Auditory localization abilities in bilateral cochlear implant recipients. *Otol Neurol*, *26*, 965–971.

Walden, B. E., Demorest, M. E., Hepler, E. L. (1984). Self-report approach to assessing benefit derived from amplification. *J Speech Hear Res*, *27*, 49–56.

Zurek, P. M. (1993). Binaural advantages and directional effects in speech intelligibility. In G. A. Studebaker & I. Hochberg (Eds). *Acoustical Factors Affecting Hearing Aid Performance* (2nd ed.). Boston, MA: Allyn and Bacon.