Timbral Recognition and Appraisal by Adult Cochlear Implant Users and Normal-Hearing Adults

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Abstract
The purpose of this study was to examine the appraisal and recognition of timbre (four different musical instruments) by recipients of Clarion cochlear implants (CIS strategy, 75- or 150-μsec pulse widths) and to compare their performance with that of normal-hearing listeners. Twenty-eight Clarion cochlear implant users and 41 normal-hearing listeners were asked to give a subjective assessment of the pleasantness of each instrument using a visual analog scale with anchors of "like very much" to "dislike very much," and to match each sound with a picture of the instrument they believed had produced it. No significant differences were found between the two different pulse widths for either appreciation or recognition; thus, data from the two pulse widths following 12 months of Clarion implant use were collapsed for further analyses. Significant differences in appraisal were found between normal-hearing listeners and implant recipients for two of the four instruments sampled. Normal-hearing adults were able to recognize all of the instruments with significantly greater accuracy than implant recipients. Performance on timbre perception tasks was correlated with speech perception and cognitive tasks.

Key Words: Appraisal, cochlear implants, hearing loss, music, recognition, timbre

Abbreviations: bpm = beats per minute, CI = cochlear implant, CIS = continuous interleaved sampling, DAT = digital analog tape, NH = normal hearing, SLT = sequence learning test, VMT = visual monitoring task

Because music is a pervasive art form and social activity in our culture, it is not surprising that some cochlear implant (CI) recipients express interest in listening to music following implantation. However, implant devices have been designed primarily to enhance speech recognition; some technical features of the device particularly suitable for speech perception seem less so for music listening. Consider some of the similarities and differences between these two sound forms. Speech is a discursive form of communication made up of acoustic signals with key elements of frequency, intensity, and timbre (tone quality) that change as a function of time. In speech, timbre is a factor with regard to voice quality (consequently a factor in speaker recognition) and also phoneme perception (consequently a factor in speech recognition).

Music, like speech, has key elements of frequency, intensity, and timbre that change as a function of time, but music is a nondiscursive form of communication that differs greatly from speech with regard to function. In music, timbre assists the listener in distinguishing one musical instrument from another. Even without name recognition of different instruments, normal-hearing listeners can recognize timbres as emanating from different sound sources and may associate the quality of particular instruments with specific emotional content, stereotypic
genres, or functional usage as a result of cultural convention (Gfeller, 1991). For example, the brilliance of a trumpet fanfare is often associated with feelings of triumph or with military or state events. In contrast, the haunting, mournful sound of the French horn is likely to be used by composers of movie scores for those portions of the script that have dark or sad emotional content. These qualitative differences are important in representing emotional expression in music.

Timbre recognition or discrimination also plays an important role in pattern perception as the listener tries to organize a stream of ongoing musical information (Dowling and Harwood, 1986; Bregman, 1990). Because normal-hearing listeners can readily discriminate even subtle differences in tone quality from one instrument to the next, composers sometimes use contrasting qualities to establish a theme, variations on the theme, or contrasting themes (Bregman, 1990). In short, discrimination and recognition of differing timbres assist listeners in organizing and understanding the structural design of a musical composition.

However, a listener need not recognize the instrument producing the sound in order to derive tremendous pleasure from music. The tone quality, or timbre of the sound, if perceived as a pleasurable or interesting sensory experience, can be intrinsically satisfying (Dowling and Harwood, 1986). The judged beauty or pleasantness of different timbres is subjective in nature but is particularly relevant with regard to the aesthetic value or enjoyment of music. For example, a fifth grader may play the Brahms “Lullaby” on her violin following a year of lessons, and most likely only the child’s nearest relatives will characterize the performance as beautiful to hear. The same Brahms “Lullaby” (same pitches in the same sequence), played by a violin virtuoso, can bring rapt attention and enormous pleasure to most listeners. Difference in tone quality is also an important factor in judgment, even in comparisons among performers considered to be experienced professionals. For example, the vocal quality of professional operatic singers, country western singers, or hard rock singers differ significantly, but the extent to which these three divergent timbral qualities are considered pleasurable will vary considerably from one listener to the next. Thus, the timbre of music, as it contributes to the aesthetic or enjoyment value of the sound, is a highly subjective yet critical component in music listening. Consequently, the appraisal of the sound quality, as well as accuracy of recognition, is worthy of consideration when determining a CI recipient’s satisfaction with the device.

Timbre, “that attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar” (cited in Von Bismarck, 1974, p. 197), is multidimensional in nature and depends most strongly on spectrum. Definitions of timbre include two important types, acoustic and psychological (Wedin and Goude, 1972). Acoustic definitions relate the variation of timbre to physical characteristics in the sound signal. Psychological definitions consist of descriptions proceeding from the listener’s experience. Several perceptual mechanisms and different physical attributes are involved during different timbre-related listening tasks such as recognition, classification, discrimination, and preference of musical instruments, and the acoustic properties depend upon the context in which the sound is heard (Handel, 1995).

Terms such as timbre, tone color, or tone quality are sometimes used informally in an interchangeable fashion, although there are more restrictive uses of these definitions (Kendall, 1986; Strong and Plitnik, 1992). Timbre (or tone color) is the term used by some as that multidimensional attribute of a steady tone that assists the listener in distinguishing it from other tones that have the same loudness and pitch (Strong and Plitnik, 1992). The differences heard from one instrument to the next are the result of a host of acoustic properties, including the frequency spectrum, the onset and offset transients, and inharmonic noise associated with sound production (Wedin and Goude, 1972; Grey, 1977; Handel, 1995). Successive changes (in contrast to isolated tones) and fusions of pitch, loudness, and tone color are described by some as tone quality (Kendall, 1986; Strong and Plitnik, 1992). Transitions between one sound and the next, timing and rhythmic framework, and the introduction of vibrato or tremolo can contribute to tone quality (Kendall, 1986; Strong and Plitnik, 1992; Handel, 1995).

Psychoacoustic studies regarding timbral perception of normal-hearing persons, with and without musical training, have emphasized the role of the physical attributes of the sound in identification accuracy, similarity judgments, and ratings. Often psychoacoustic studies examine perception of timbre using isolated notes (Kendall, 1986; Parnutt, 1989; Handel, 1995). Wedin and Goude (1972) tested subjects with two versions of recordings of nine real instruments.
playing a sustained note of 440 Hz for about 3 seconds. One version had normal attack while the other had the attack and decay eliminated. Seventy psychology students (classified as musically sophisticated or naive by their ability to correctly identify at least five of the nine instrumental sounds) were asked to judge the similarity of pairs of tones. Wedin and Goude concluded that perceptual similarity under the particular testing conditions (tones presented with and without onset transients) could be explained in terms of a three-dimensional model identified with the relative strength of the harmonic partial tones.

Grey (1977) used multidimensional scaling to evaluate the perceptual relationship among 16 instrumental timbres using computer-synthesized stimuli based on actual instrumental tones. The participants, “musically sophisticated” adults with experience in advanced instrumental performance, conducting, or musical composition, were asked to judge the similarity between every pair of notes. Grey determined that listeners used three dimensions to make their judgments: spectral energy distribution, the presence of synchronicity in the transients of the higher harmonics, and the presence of low-amplitude, high-frequency energy in the initial attack. A subsequent study by Grey and Gordon (1978), using modified sets of instrumental tones, supported the three-dimensional scaling solution of the 1977 study. These psychoacoustic studies highlight the multidimensional nature of timbre and the physical aspects that contribute to perceptual differences in timbre recognition. However, they do not address the subjective description or evaluation of timbre.

Other studies of timbre perception by normal-hearing persons have emphasized the subjective experience of the listener to a greater extent than the specific physical attributes of the sound wave. Studies of psychological descriptions of musical timbre frequently involve verbal descriptors or subjective ratings of the timbre or tone quality. In particular, several studies have investigated the utility of verbal descriptors in rating or describing timbral qualities as perceived in isolated notes. Von Bismarck (1974) attempted to extract from the timbre percept those independent features that can be described in terms of verbal attributes using semantic differential and factor analysis. A sample of 35 different sounds representing human speech and some musical sounds were rated by musicians and nonmusicians. They rated each stimulus using 30 pairs of polar opposites (such as dark-bright or smooth-rough). A factor analysis indicated that these sounds could be almost completely described if rated on largely independent scales of dull/sharp (44% of the variance), compact-scattered (26% of the variance), full-empty (9% of the variance), and colorful-colorless (2% of the variance).

Pratt and Doak (1976) devised a subjective rating scale for quantitative assessment of timbre using the concept of the semantic differential. They devised three scales: dull/brilliant, cold/warm, and pure/rich. They subsequently tested whether or not these scales were independent and whether the adjectives selected were useful in making genuine distinctions between sounds. Twenty-one participants (described as primarily students and university staff, musical training not specified) were asked to rate six synthesized sounds of differing harmonic content with the same loudness, pitch, and envelope using the three rating scales. Pratt and Doak reported that a verbal subjective rating scale can be useful in differentiating between certain sounds of varying harmonic content, but that the dull/brilliant scale offered the greatest reliability. They also noted the similarity between their results and those of Von Bismarck (1974) with regard to the utility of verbal descriptors, as well as the similarity of those adjective pairs determined to be most informative. These measures do not address directly personal appraisal or enjoyment of the timbre; rather, they describe qualities. For example, two listeners may each describe a popular singer like Bob Dylan's voice as nasal in character, yet may have very different attitudes regarding the pleasantness of his vocal quality.

As previously noted, in these and other psychoacoustic studies, perception is typically examined in response to isolated tones presented out of context. While the use of isolated tones has obvious advantages with regard to focusing on physical attributes of the sound wave, extrapolation of psychophysical results to sound in a musical context can be problematic (Parncutt, 1989; Handel, 1995). This point is illustrated by Kendall's (1986) research in which musicians and nonmusicians responded to a matching procedure for trumpet, clarinet, and violin both for whole phrases and also for single notes. The phrases and single notes were presented in several forms, some that had been edited with regard to transients and others that were in natural and complete format. Kendall found that the whole phrase context yielded significantly higher means than the single-note context.
for matching accuracy. Kendall used these data as well as philosophical argument to make a case for using whole and musically sound stimuli in order to achieve greater external validity.

With regard to the use of musical phrases rather than isolated notes, Handel (1995) noted that the transients connecting notes might contain much of the acoustic information for identification, and that representation of an instrument by one note fails to address the consideration, and that representation of an instrument by one note fails to address the considerable variance found for even a single instrument (due to factors such as register, bowing vs. plucking, blowing pressure, special articulation, etc.). Furthermore, the contextual circumstances introduced in testing can have an important impact on timbral perception. Therefore, the simplest valid context may be a single instrument playing a short phrase (Handel, 1995).

Additional factors must be taken into account when considering timbral perception through an assistive device such as the CI. Because timbre is largely the result of particular spectral characteristics of the sound wave, the manner in which different types of CIs code those spectral characteristics has implications for the recognition and enjoyment of musical instruments. Some implants use a digital coding strategy called speech feature extraction and other devices use an analog strategy. In devices using speech feature extraction (e.g., Nucleus device), the different coding strategies transmit particular aspects of the sound wave (Blamey et al., 1978). For example, one strategy may transmit to the recipient the fundamental frequency plus only the first and second formants, while a different strategy may include higher formants in addition to the fundamental, first, and second formants. Because the timbral quality of musical instruments is affected by upper harmonics, appreciation or recognition of musical instruments may be impeded by strategies that include only first or second formants. Those devices that use an analog strategy (e.g., the Ineraid or Richards device) present the entire waveform to the listener, rather than extracting particular features of the sound wave (Edington, 1980). It is possible that the information transmitted by some types of devices or coding strategies (e.g., those strategies presenting the full waveform or those with more rapid pulse rate) would result in a more acceptable or “natural” quality of sound during musical listening.

To date, only a few studies have investigated appraisal (or likability) of various musical timbres by implant recipients. Gfeller and Lansing (1991) compared evaluative ratings of timbre by implant recipients using either the Nucleus Wearable speech processor (FOF1F2 feature extractor; N = 10) or the Ineraid (analog coding strategy; N = 8). The participants listened to nine short solo melodies of familiar songs such as “Stars and Stripes Forever” or “Pop Goes the Weasel.” Each instrument was presented on a different tune representing a portion of the frequency range and stylistic features commonly associated with that instrument. For example, the saxophone is often associated with jazz and popular styles of music, while brass instruments are often featured in marches and fanfares. Different ranges also present more characteristic tone quality for different instruments. In response to these nine solo excerpts, participants were asked to circle adjective descriptors, including evaluative descriptors such as beautiful, pleasant, unpleasant, and ugly. The percentage of respondents who assessed each instrument as beautiful or pleasant (the two most positive descriptors within the list) was calculated. Ineraid users selected the two positive descriptors for a larger percentage of musical instruments than did the Nucleus users. While these solo melodies do reflect the sorts of musical selections that each instrument is likely to play, these stimuli also include enormous variability from one instrument to the next with regard to frequency range, pitch sequence, rhythmic structure, style, tempo, and phrasing. Each of these factors could contribute to the subjective assessment, thus making it difficult to determine the contribution of the instrument’s basic tone quality or timbre to the evaluation.

A case study of one professional musician who used the Ineraid device indicated that some musical instruments had a “new sound quality” with the implant, compared with memory for the instrument’s sound (Dorman et al., 1991). For instance, the musician described brass instruments, when played loudly, as producing a “splat-ter” of tone. Most string and reed instruments sounded pure at all volume levels, and the violin, viola, and flute were particularly pleasant when heard through the implant. This anecdotal account offers a global description of a host of listening experiences, ranging from listening to entire ensembles to solo performances in a variety of listening situations, so no conclusions can be drawn regarding the particular variables within the musical stimuli or listening environment that influenced this individual assessment. Furthermore, while there is an obvious advantage of asking musicians to describe their listening experiences, since they can often
describe the sound more completely and technically, it is important not to overgeneralize the response of musicians to the at-large implant recipient population since musicians are known to respond differently from nonmusicians on a number of music perception tasks, including timbral perception (Kendall, 1986).

Schultz and Kerber (1994) asked eight CI users (MED-EL) and seven normal-hearing persons (not described with regard to musical background) to give “subjective impressions, elicited by different instruments. The candidates had to rate the sounds of 25 different instruments” (p.326), which were produced by a synthesizer and represented different families of sound production (wind, percussion, strings). Ratings were collected using a 5-point rating scale (ranging from 1 point for “appeals absolutely not” to 5 points for “appeals very much”). Schultz and Kerber stated that instruments “that sound pleasant to normally-hearing, also sound pleasant to CI-users. Rating by CI-users, however, is generally lower, which is statistically significant in the cases” of wind instruments (i.e., mean score of a family of eight different wind instruments) and the sum of all 25 instruments. This small sample as a group rated string instruments as sounding more pleasant than wind instruments. The article does not specify the frequency range, pitch sequence, rhythm, or other structural characteristics of the instrumental sounds, or the manner in which the stimuli were produced, other than to indicate that synthetic sounds were used.

As can be seen, few studies exist to date regarding appraisal of various timbres by CI recipients, and those studies that do exist include either considerable variability across the different instrumental samples or provide little or no information about the structural characteristics of the stimuli, its production, format for presentation, or the musical background of the participants.

Similarly, limited data exist regarding recognition of musical instruments by CI recipients. In a study of Ineraid recipients (N = 16), participants were asked to identify five different musical instruments (voice, violin, piano, flute, and horn), first in open set and then in closed set. The majority of participants were able to identify only one or two instruments in open-set recognition (Dorman et al, 1991). However, in a closed-set format, 12 of the 16 participants were able to identify four or five instruments out of a total sample of five instruments (voice, violin, piano, flute, and horn). The authors of this study provide no specific description of the structural characteristics of the stimuli (frequency range, pitch pattern, rhythm, phrasing, etc.), the method of stimuli production, or the format for presenting the test stimuli. No information is provided regarding the musical background of the participants or their performance on other sorts of listening tasks.

Schultz and Kerber (1994) asked eight recipients of the MED-EL and seven normal-hearing persons to identify five different musical instruments (piano, violin, trumpet, church organ, and clarinet) as produced on a synthesizer from a closed set. The authors note that the instruments “were playing single-note lines” in one portion of the test and “double-voice lines” at another point, although they do not specify the frequency range, rhythmic pattern, specific pitch contour, or transmission of the stimuli. Each instrument was presented five times in random order. Schultz and Kerber report that scores did not differ significantly based on “single-note” (i.e., melody) or “double-voice” (i.e., harmony) presentation, so the scores for melody and harmony were combined. The normal-hearing persons scored “much better than CI-users,” with an average difference of 54 percent. No information is provided regarding the musical background of the participants or their performance in relation to other sorts of listening tasks.

This handful of extant studies regarding CI and timbre suggest that there are differences in appraisal and recognition of timbre that could be attributed to the design of the existing implants. Also, these data indicate that implant recipients do more poorly both in recognition and enjoyment than normal-hearing listeners. However, it is difficult to determine which factors have contributed to either appraisal or recognition, since extant studies have either failed to describe fully the nature of the stimuli or have not controlled the structural features of the chosen stimuli (e.g., pitch range or sequence, rhythm, phrasing, or prior familiarity with particular musical selections). In addition to limited information regarding the musical stimuli, the majority of these studies offer limited information about the participants regarding the musical background (or in the case of implant recipients, hearing history or their success on other listening tasks [e.g., speech perception]), which could potentially influence recognition or appraisal.

Therefore, the purpose of this study was to determine whether recipients of the Clarion CI could recognize the sounds of different musical
instruments and whether they would rate musical stimuli reflecting different timbral attributes positively or negatively. In addition, the study was designed to determine the degree to which the accuracy in identification and the appraisal of musical stimuli by implant recipients would approximate the accuracy and appraisals made by normal-hearing nonmusicians. The structural variables in the musical stimuli include three short melodic patterns representing three different sequential pitch structures and four different musical instruments representing different instrumental families. The pitch sequences are controlled across the four instruments for frequency range, pitch sequence, rhythm, tempo, and general articulatory style. In addition to determining accuracy in recognition and the appraisal of musical stimuli by implant recipients, the study was designed to determine whether individual differences in accuracy and appraisal were associated with individual differences in other indices of audiological performance (i.e., speech perception) and subject attributes that have been related to implant outcomes (e.g., cognitive abilities, demographics), as well as musical background and listening habits.

METHOD

Participants

Participants included 28 recipients of the Clarion CI and 41 normal-hearing listeners. The implant users (13 male, 15 female) ranged in age from 29 to 75 years of age with a mean age of 51 (SD = 14.0) years and presented postlingually acquired bilateral profound hearing loss prior to implantation. All participants were nonmusicians as determined through a musical background inventory (see test measures). The profile of individual CI recipients for hearing history, speech perception, and other relevant measures appears in Table 1.

The Clarion implant recipients in this study were given 3 months to acclimate themselves to that particular processing strategy and were tested at the end of that period for speech perception, psychosocial adjustment, and musical perception and enjoyment. The data for this study were taken from trial 7 (12-month follow-up visit with 3 months experience), except for those few cases in which no data were available from month 12. In those cases, data were taken from trial 5 (9-month follow-up visit with 3 months experience). Of the 28 implant users, 27 had appraisal and recognition data at trial 7 and 1 had data only up through trial 5. For the demographic variables of postlistening habits, NU-6, and vowels, 24 users had trial 7 data and 4 had only trial 5 data.

The normal-hearing participants (11 male, 30 female) were nonmusicians who ranged in age from 18 to 24 years (mean = 19.3, SD = 1.5). They were recruited through a newspaper advertisement on a volunteer basis and were informed of the testing protocol in compliance with human participants' procedures for informed consent. They were tested one time each.

Device

The Clarion CI is a multichannel implant designed with flexible speech processing capabilities (Kessler and Schindler, 1994). The implant recipients in this study used a continuous interleaved sampling (CIS) type of signal processor. The CIS has been described in some detail by Wilson et al (1993). Briefly, the processor filters the signal into eight different frequency bands and the output of the filter is used to modulate a series of biphasic current pulses (Wilson et al, 1993). Those signals whose energy is concentrated at one harmonic will excite one band to a greater degree than any other. Signals with complex harmonic structures (e.g., as found in musical instruments) may excite a number of bands and therefore a number of electrodes.

In this study, recipients were programmed with a digital processor, using monopolar electrode stimulation, in either sequential (i.e., channels 1 through 8 are stimulated in sequence) or nonsequential (i.e., channels 1 through 8 are stimulated nonsequentially, such as in the order 1, 8, 2, 6, etc.) modes at two different pulse widths: 75 μsec and 150 μsec. A longer pulse width (150 μsec) results in lower detection thresholds, so lower current levels can be used. With the Clarion implant, pulse width is the primary determinant of pulse rate (for a fixed number of channels). Therefore, a longer pulse...
width also results in a slower pulse rate. To date, no empirical data are available regarding the effects of these two pulse widths transmitted through the Clarion CI on musical perception.

**Test Schedule**

In compliance with the multiproject protocol, implant recipients were tested on a variety of measures four times at 3-month intervals (following 3 months of implant use with a particular pulse width) for the 12 months following implantation. There was some variability among participants with regard to the sequential order of the two pulse widths over the 12-month trial. Because the pulse width manipulation was initiated primarily with regard to speech perception, and because preliminary analyses indicated no significant differences between the two pulse widths for timbral perception, the data presented in this paper are those taken 12 months following initial Clarion use (in the case of one participant, no data were available from month 12, and so 9-month data were used). Normal-hearing participants were tested during a single test session that lasted approximately 1 hour.

**Auditory Stimuli**

A variety of stimuli have been used in past studies of timbral perception, although isolated tones are typically used in multidimensional scaling. While multidimensional scaling provides valuable information regarding the contribution of physical attributes to the quality of the sound, such a testing paradigm requires a relatively lengthy time period for testing (Radocy and Boyle, 1988). Further, there are difficulties extrapolating the findings from studies that use isolated tones to contextualized tasks such as melodic phrases (Kendall, 1986; Parncutt, 1989;
Handel, 1995). In addition, multidimensional scaling does not measure subjective appraisal or enjoyment, an important consideration when it comes to the satisfaction with the implant in everyday music listening and a primary focus of this study.

Therefore, given a highly restrictive testing schedule (which precluded multidimensional scaling) and the desire to gather response to stimuli that would more nearly reflect satisfaction in everyday listening, we chose as stimuli simple and short melodies prepared specifically for the study, as opposed to isolated and synthetic tones (Handel, 1995). However, we sought a greater measure of consistency and control over the stimulus than found in prior studies of timbre perception by implant recipients (Dorman et al, 1991; Gfeller and Lansing, 1991; Schulz and Kerber, 1994), which included either a variety of melodies representing different ranges, rhythms, and other features, or no specified structural characteristics. Therefore, we prepared stimuli that would be consistent across the four different instruments for frequency range, specific pitch sequence, tempo, phrasing, and articulation. The specific structural characteristics are described below.

**Pitch Sequences**

The test stimuli were presented on cassette tape and consisted of three different melodic patterns (Fig. 1), eight measures in length, in the frequency range of 261 to 523 Hz, played at the tempo of a quarter note = 60 beats per minute, and structured as follows: (a) a one-octave C major scale, (b) a one-octave C major arpeggio, and (3) a simple melody composed specifically for this study, using frequencies found within the scale and arpeggio. A C major scale is a sequence of pitches with changes of whole and half steps (two or one semits) based on just temperament beginning on the note middle C. The stepwise changes in frequency represent those intervalic changes commonly used in music based on Western tonality and those intervalic changes found on the piano keyboard. The arpeggio is made up of the following sequence of pitches: C4, E4, G4, and C5 (skipping rather than stepwise pitch changes), and it outlines a triad, a common harmonic unit in Western music. Examples of both stepwise and skipping intervalic changes were selected in part because they represent common melodic patterns within Western music. Prior studies have also indicated perceptual differences in response to different types of intervalic change or direction (Kendall, 1986). In addition, prior testing (Gfeller and Lansing, 1991, 1992) indicated that some small stepwise changes may be difficult for some implant recipients to perceive, which could potentially influence appraisal.

The sequence of pitches included in the third pattern (titled “melody”) more nearly represented a musical melody than did either the major scale or arpeggio (in isolated forms, the scale and arpeggio are primarily used by musicians for practicing technical proficiency), but it was made up of a combination of stepwise and skipping intervalic changes found in the scale and arpeggio, respectively. The three melodic patterns were presented on four different solo instruments as described in the section that follows.

**Timbres Presented**

Each of the melodic patterns was played as a solo on each of the following four musical instruments: clarinet, piano, trumpet, and violin (see Fig. 2 for spectral analyses of the first note of the scale [C 261 Hz] played by each of four different instruments). These four instruments were chosen because they can be played in a similar frequency range (thus making it possible to present all stimuli in a consistent pitch range) and because each is a commonly recognized example of an instrumental family with a particular principle of tone generation.

The trumpet represents the brass family, in which sound is produced by a lip reed (the air column is excited by the vibrating lips of the player against a cup-shaped mouthpiece) and sections of cylindrical and conical tubing. All harmonics are present in the spectra of brass instruments, but the trumpet bell assists in producing a louder, clearer tone than some other brass instruments and changes the resonance frequencies, as well as reduces the number of resonances that are present (Strong and Plitnik, 1992).
Figure 2 Spectral analysis of the first note of the scale (C 261 Hz) played by each of four different instruments (clarinet, piano, trumpet, and violin).

The clarinet is a member of the woodwind family and uses a vibrating reed to produce oscillations in the air column. In general, the clarinet tones show predominantly odd harmonic structure up to around 2000 Hz. Beyond that frequency, even and odd harmonics appear to approximately the same extent (Strong and Plitnik, 1992).

The violin is the highest pitched instrument of the string family. Within the string family, a string fixed at both ends is the primary vibrator, and most of the sound energy is radiated by the body of the instrument and with a smaller amount from the string. All of the partials are present with the exception of those having a node at the point of excitation (Strong and Plitnik, 1992).

The piano is an example of a percussive string instrument and as such has the following characteristics: primary vibration by a string fixed at both ends, all partials present with some exceptions, most of the energy is radiated by the body, and inharmonic partials are quite apparent from some free strings (Strong and Plitnik, 1992).

It is important to note that the aforementioned descriptions of the four instruments used in the study are overviews of the prototypical spectra. In actual sound production, the spectra of these instruments vary dramatically depending on factors such as register (the pitch range being played), bowing force, string tension, reed size, blowing pressure, type of articulations (such as staccato, or detached attack of each note versus a legato or smooth attack of each note), and instrument construction.

Production of the Timbral Stimuli

Professional musicians (a trumpeter, clarinetist, violinist, and pianist) recorded the three different pitch sequences in a professional recording studio onto a DAT tape. To reduce the structural variability of the phrases from one instrument to the next, each instrumentalist was instructed to play in concert C pitch, maintain uniform phrasing and articulation (i.e., legato tonguing), maintain a steady and uniform tempo of a quarter note = 60 bpm (a metronome using a flashing light was used to assist the different musicians in maintaining a consistent tempo), and to play at an intensity of mezzo forte (medium loudness).

The stimuli for the appraisal task were prepared as follows: the three sequences (scale, arpeggio, and melody), as played by each of the four instruments, were copied onto a cassette tape (Certron brand) three times each in a random order. The stimuli for the recognition task were prepared as follows: the melody sequence was recorded in a random order onto a cassette tape three times for each of the four instruments.

Music Test Measures

Appraisal Rating

Appraisal, a subjective rating of the pleasantness of the timbral samples, was gathered using a graphic rating scale, the procedures advocated for use in obtaining ratings or preferences in the judgment and decision literature (e.g., Anderson, 1982). The graphic rating approach was adopted because it minimizes the problem of residual number preferences (Shanteau and Anderson, 1969) that can compromise numeric rating procedures. To rate the musical stimuli graphically, subjects responded on a visual analog scale 100 mm in length with anchors of “like very much” (100 mm) to “dislike very much” (0 mm). Participants were asked to place a hash mark along the continuum to represent how well they liked each musical pattern. Each melodic
pattern for each of the four instruments was presented three times in random order, with subjects rating each presentation.

Recognition

Participants were asked to identify the source of each stimulus by pointing to a picture of the instrument that they believed had produced the sound. While a matching paradigm (that is pairing the two most “like” stimuli out of a larger array of sounds) might seem a superior method to recognition for reducing the impact of prior knowledge of instrument names, matching requires a considerably longer testing time than was available. Furthermore, the impact of formal musical training, and thus greater knowledge of instrument names, is not completely eliminated in a matching paradigm (Kendall, 1986).

Because knowledge of the formal names of musical instruments may vary from one person to the next depending on past experiences or formal musical training, participants were not asked to name the instrument heard. Instead, they were provided with a poster illustrating an array of 12 different commonly known musical instruments (closed set, uneven match) from which to choose. While it is still possible that an individual may be unfamiliar with the physical characteristics of an instrument, the attribution of particular timbral qualities to a physical source is believed by some to be an important factor in timbral recognition (Colwell, 1992). Furthermore, musical instruments commonly known by the general public were selected as stimuli to increase the likelihood of familiarity with the instrument’s timbre.

Each of the four instruments was presented three times, in random order. Participants were assigned 1 point for each correct answer. The range of scores for each instrument was 0 (none correct) to 3 (all correct).

Musical Background

To account for past training and experience, participants completed a survey on past musical training and pre- and postimplant listening habits. The questionnaire (Gfeller and Lansing, 1991) uses a cumulative point system to quantify years of participation in a variety of musical experiences and self-reported enjoyment of music. Questions included the extent of preimplant experience in three different types of musical activities: (a) music lessons, (b) participation in musical ensembles, and (c) music appreciation classes. One point was tallied for each type of music activity in which the person participated, and points were awarded for the length of time spent in each activity. Points for musical participation in lessons and classes ranged from 0 to 15 (0 = no involvement, 15 maximum for measure of type and length of involvement).

Points were also assigned for the amount of time CI recipients spent each week listening to music before hearing loss and following implantation. Additionally, subjects rated musical enjoyment prior to the onset of hearing loss and following CI use on a 4-point Likert-type scale. Points ranged from 2 to 8 for preimplant listening habits (extent of listening and enjoyment) and 2 to 8 for postimplant listening habits.

Cognitive Test Measures

All of the implant recipients enrolled in the Iowa research protocol complete an extensive preimplant psychological evaluation that includes a number of tests of specific cognitive abilities. These tests of cognitive ability were included to identify participant attributes that might predict audiologic benefit by implant users. Because implant candidates are profoundly deaf, all of the experimental cognitive measures require only visual input and motor output. Based on the research of Knutson et al (1991) and Gantz et al (1993), preimplant scores for two tests of cognitive ability were included in the present study. The Visual Monitoring Task (VMT), an experimental task developed by the Iowa CI research team, requires participants to view a computer screen on which single-digit numbers are presented at a rate of one per second (VMT1) or one every 2 seconds (VMT2). Whenever the displayed number reflects an even-odd-even pattern, the participant is to respond by pressing a single key on the computer keyboard. The task requires that participants maintain three characters in working memory as well as make an accurate identification of the displayed character. Using a signal detection algorithm to credit correct responses and correct rejections, and to adjust for errors (omissions and false alarms), this measure has been highly successful in predicting audiologic success of implant use. In the Gantz et al (1993) work, the slower presentation version (i.e., VMT2) was the best nondemographic predictor of speech perception, and for that reason was included as a possible predictor of recognition accuracy and appraisal in the present study. It cannot be
assumed, however, that the same predictor of speech perception will hold true for music perception. Therefore, the VMT1 (i.e., the task with the faster presentation rate) was also included in the current data analysis.

The Sequence Learning Test (SLT) was adapted from the cognitive research of Simon and Kotovsky (1963). The SLT requires subjects to produce the next four characters in a sequence after viewing a train of sequentially organized characters. Because melodic stimuli involve sequential relationships, and the SLT requires analyses of sequential relationships, the task was included in the present research, with scores reflecting the total number of sequences successfully completed.

Because memory may play a role in the ability to respond to musical stimuli, a test of memory was included as a third index of cognitive ability. The selected task is an experimental test of associative memory that was developed specifically for the Iowa implant project would not require any auditory input and would not be based on language. This task involved the presentation of 12 two-dimensional monochromatic geometric figures on a computer screen; each figure is paired with a single number (eight numbers are associated with one figure each and two numbers are associate with two figures each). For each figure, the participant is required to identify the number that goes with each figure; duration of presentation prior to responding is participant determined. Following participant response, they receive immediate feedback and are given 8 seconds to simultaneously view the figure and the correct number. The entire series of figure-number pairings is repeated 10 times, with the score being the mean number of correct identifications across the 10 trials.

Speech Perception Test Measures

Measures of speech perception were included as part of the multiproject program to assess the ability to recognize consonants and features of articulation in nonsense syllable contexts and monosyllables in isolation. All speech tests were presented in an audition-only condition in sound field at a level of 70 dB SPL. Several speech perception measures were examined in relation to participant performance on the timbre appraisal and recognition tasks. Those included the Iowa NU-6 Test (Tyler et al, 1983) and the Iowa Vowel Test (Tyler et al, 1986).

Iowa NU-6 Test

This test presents 50 re-recorded words of the NU-6 Monosyllabic Word Test (Tillman and Carhart, 1966) and is used to evaluate open-set recognition. The number of correct phonemes and number of correct words are scored.

Iowa Vowel Test

This test consists of nine vowels presented in /h-vowel-d/ words (i.e., /Heed/, /Had/) presented six times each in random order. Analysis consists of percent phonemes correct.

Music Test Procedures

Participants were tested individually in a quiet room while seated behind a table. The test stimuli were presented via a Hitachi portable component audio cassette system (model MS-W600H). The cassette system was placed approximately 1 foot in front of each participant with the right and left speakers set at a 45-degree angle from the front of the participant's face. Presentation of stimuli via a tape recorder, in free-field, represents a common mode of presentation in everyday music listening experiences. The music was presented at a constant volume level on the cassette player for all participants. However, the implant recipients were allowed to adjust their processor if they found the music to be uncomfortably loud. Sound level measurements were taken at the level of a CI recipient's headpiece to determine the intensity of the musical stimuli. The following sound level ranges were obtained for each instrument across the entirety of the three musical phrases: violin = 66-74 dB SPLC, trumpet = 70-76 dB SPLC, clarinet = 70-73 dB SPLC, and piano = 70-76 dB SPLC.

Participants completed the rating task first and then the recognition task. At the start of the recognition task, participants were given the poster illustrating 12 different musical instruments. They were told that they may or may not hear all of the instruments on the poster and that they may hear some instruments more than once. No feedback on accuracy was provided during or following testing since feedback to specific items would change the procedures from a test of accuracy without any special training or preparation to an acquisition or learning paradigm (which was beyond the scope of this particular study).
RESULTS

This study compared recognition accuracy and appraisal ratings of timbre as presented in simple melodic context by CI recipients as compared with normal-hearing listeners. Particular focus was given to the characteristics of the most and least successful implant recipients for timbral appraisal and recognition. Because all of the CI recipients were fitted with the two contrasting pulse widths over the course of 12 months, as part of the multi-project protocol (primarily as a manipulation for speech recognition), an initial analysis was completed to rule out possible differences between pulse widths (75 µsec vs 150 µsec) for either appraisal or recognition. The analysis revealed no significant differences between pulse widths for either measure; therefore, the data reported in this paper include the combined scores of both pulse widths following 12 months of Clarion use.

After determining no significant differences for the two pulse widths, t-tests for paired samples were computed to determine whether significant differences existed on appraisal ratings for the three structurally different pitch sequences: scales, arpeggios, and melodies. A significant difference (p < .01) was found between the scale and the arpeggio on one instrument, the clarinet, on the measure of appraisal for only the CI recipients. However, both groups (CI recipients and normal-hearing participants) did appraise the newly composed melody (which contained both types of intervalic changes) significantly higher (p < .01) than either the scale or the arpeggio across all four instruments. This suggests that the structural nature of a pitch sequence (in this case, a sequence that sounds more like a melody than like a technical exercise) can have an impact on appraisal. However, the limited differences across all of the instruments between the arpeggio and scale indicate that the class or magnitude of intervalic changes, per se, was of little consequence in these particular tasks. Therefore, a composite score (which included the scale, arpeggio, and melody), the most comprehensive representation of each instrument, was used as the primary dependent variable for analysis of appraisal and recognition.

Measures of appraisal were correlated with the VMT and music listening habits following implantation while measures of recognition were correlated with the VTM and music listening habits before implantation.

To more thoroughly examine if there are particular characteristics of those implant recipients most successful with regard to timbre perception, the sample of CI recipients was broken into tertiles of the highest, middle, and lowest performers on the two dependent variables of recognition and appraisal. These tertile ranks were then examined in relation to speech perception measures and cognitive testing outcomes as well as other individual characteristics.

Appraisal

To determine whether significant differences existed between the implant users and normal-hearing listeners, t-tests were conducted for appraisal (likability) of each of the four instruments on the composite score of all three pitch sequences. The intra-rater reliability for appraisal of each of the four instruments ranged from .78 to .91 for normal-hearing listeners and from .89 to .92 for implant recipients. To provide more stringent control of type I errors for multiple t-tests, only those comparisons with p values of .01 or smaller were reported as significant.

Normal-hearing listeners rated both the trumpet and violin as significantly more likable than did the implant recipients (p ≤ .01) (Fig. 3). In general, implant recipients demonstrated a more restricted and generally lower range of likability scores (range of 38.83 to 52.33 for the four instruments) than did normal-hearing adults (range of 40.17 to 52.33 for the four instruments). The overall mean appraisal score (all four instruments) for implant recipients was 47.31 and for normal-hearing listeners was 57.03. T-tests for paired samples were calculated to compare appraisal of instruments within each group.

![Timbral - Likability](image-url)

Figure 3 Comparisons of appraisal for the clarinet, piano, violin, and trumpet between the normal-hearing participants and the cochlear implant recipients.
Figure 4 reflects the greater number of significant contrasts identified for the normal-hearing listeners than for implant recipients.

Correlations were calculated for appraisal (the average of all musical instruments and all pattern types) and participant characteristics. Only the VMT administered at the one character per 2-second rate (VMT2) and the postimplant listening score were statistically significantly correlated with the appraisal score \((r = .59, p = .0046\) and \(r = .49, p = .0082\)). The VMT administered at the one character per second rate did not approach statistical significance. Although not statistically significant by conservative standards, moderate correlations were found between appraisal and musical background \((r = .41, p = .0284\)).

Tertile data were calculated by ranking appraisal scores and dividing the data into three groups. Nine participants were included in the top tertile, 10 in the middle tertile, and nine in the bottom tertile. Comparisons for the tertile rankings were made using a one-way analysis of variance for normally distributed variables and the Kruskal-Wallis test for non-normally distributed variables. Follow-up pairwise t-tests were performed for significant variables; in cases where variances are unequal, \(p\) values are reported for the unequal variance (Aspin-Welch) version of the t-test (Dixon and Massey, 1983). The most significant difference between the groups was for the VMT at the one per 2-second rate (VMT2; \(p = .0065\)). Statistically significant differences existed between both the high and the low tertiles \((p = .0105)\) and the high and middle tertiles \((p = .0493)\). The only other significant difference was for the VMT at the one per second rate (VMT1; \(p = .0493\)). However, this difference was attributable to the difference between the high and low tertile groups only \((p = .0376)\).

**Recognition**

Normal-hearing adults were able to identify all of the instruments with significantly greater accuracy than implant recipients (Fig. 5). Implant users recognized the different instruments in descending order from most to least accurate as follows (range of 3 for all correct to 0 for none correct): piano \(X = 1.7\) (SD = 1.08), violin \(X = 1.21\) (SD = .79), trumpet \(X = 1.00\) (SD = .90), and clarinet \(X = .61\) (SD = .63). Normal-hearing adults recognized the instruments in the descending order from most to least accurate: piano \(X = 3.0\) (SD = 0.00), clarinet \(X = 2.6\) (SD = .74), trumpet \(X = 2.1\) (SD = .99), and violin \(X = 2.0\) (SD = 1.2). Normal-hearing listeners were more consistent in recognition responses than implant recipients. For the normal-hearing listeners, the average number of identical responses ranged from 2.44 for the trumpet to 3.0 for the piano. The implant recipient's average responses ranged from 1.57 for the trumpet to 2.25 for the piano. Figure 6 presents data for accuracy by normal-hearing listeners and by CI recipients \((p < .01)\).

Because the distribution of the number of instruments recognized were highly non-normal for most of the instruments, t-tests could not be used to compare means. Instead, nonparametric exact permutation tests (Gibbons, 1985)
### Table 2: Appraisal Scores by Tertiles*

<table>
<thead>
<tr>
<th>ID</th>
<th>Speech Measures</th>
<th>Listening Habits</th>
<th>Musical Background Score (0-15)</th>
<th>Cognitive Measures</th>
<th>Appraisal Score</th>
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<td></td>
<td>Nu-6 Test</td>
<td>Iowa Vowel Test</td>
<td>Pre-implant (2-8)</td>
<td>Post-implant (2-8)</td>
<td>VMT1 VMT2</td>
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</table>

*Speech measures, listening habits, musical background scores, length of deafness, cognitive measures, and appraisal scores for cochlear implant (CI) recipients. Average appraisal scores for normal-hearing (NH) participants are presented for comparison. **Data not available.

** were used to determine whether the distributions of the number of instruments recognized were the same for normal-hearing listeners and implant recipients for each instrument and whether they were the same for different instruments within each group. Again, only those comparisons with p values of .01 or smaller were reported as significant. Not only were normal-hearing listeners significantly more accurate than the implant recipients in their recognition of all four instruments, but their errors showed specific and predictable
patterns representing instrumental family types. As Table 3 indicates, normal-hearing listeners can reliably identify clarinet, piano, trumpet, and violin in wind, percussion, brass, and string families, respectively, but cannot reliably identify instruments within brass, wind, and string families. Implant wearers can reliably place the piano in the percussion family but frequently confuse it with the marimba. They place the trumpet in the brass family two times in three and place it in the wind family one time in five. The clarinet is distinguishable from percussion instruments but is confused almost at random with other winds, brasses, and strings. The violin is identified as a string instrument almost 67 percent of the time, is rarely confused with percussion instruments, but is frequently confused with brass and wind instruments. In short, errors by normal-hearing listeners tend to be within the correct instrumental family, while implant recipients tended to show more diffuse error patterns.

Correlations were calculated for recognition (of all instruments combined) with age, length of profound deafness, musical background, and music listening habits before and after implantation. With an alpha set at .01, only the preimplant listening score and the VMT administered at the one character per second rate (VMT1) were statistically significant (r = .58, p = .0071 and r = .51, p = .0052). The VMT administered at the one character per 2-second rate approached statistical significance (r = .52, p = .0154). The other correlations were rela-
Table 4 Recognition Scores by Tertiles*

<table>
<thead>
<tr>
<th>ID</th>
<th>Speech Measures</th>
<th>Listening Habits</th>
<th>Musical Background Score (0-15)</th>
<th>Length of Deafness (Yr. Mo)</th>
<th>Cognitive Measures</th>
<th>Recognition Score</th>
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<td>Iowa Vowel Test</td>
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<td>Post-implant (2-8)</td>
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</table>

Mean 66.6 65.4 6.3 4.1 2.1 7.8 0.98 1.10 23.0 41.9 1.64
SD 14.0 13.5 1.1 1.5 2.0 8.6 0.95 0.62 8.0 20.5 42

C19 77.0 24.0 7.0 8.0 5.0 15.0 0.49 1.13 23.0 31.5 1.25
C125 59.0 46.0 8.0 2.0 1.0 2.3 0.67 0.11 28.0 15.7 1.25
C16 55.0 80.0 8.0 6.0 3.0 5.5 1.46 1.36 38.0 47.4 1.25
C128 69.0 85.0 4.0 4.0 1.0 19.0 0.71 0.49 26.0 80.1 1.00

Mean 59.6 65.1 6.2 4.3 4.1 8.4 -0.18 0.21 22.0 44.9 1.10
SD 22.4 23.4 1.5 2.1 2.7 9.3 1.90 1.33 8.1 20.9 1.3

C121 38.0 46.0 4.0 ** 7.0 58.0 ** ** 13.0 15.8 0.75
C127 62.0 76.0 3.0 3.0 0.0 45.0 0.78 0.52 14.0 25.0 0.75
C118 44.0 48.0 3.0 5.0 0.0 34.0 0.63 0.42 23.0 47.5 0.75
C110 10.0 41.0 2.0 2.0 0.0 2.0 -1.26 2.56 19.0 25.7 0.75
C17 73.0 74.0 5.0 4.0 5.0 0.5 0.09 1.36 29.0 50.8 0.75
C11 8.0 30.0 3.0 2.0 0.0 1.0 -2.32 -3.73 5.0 15.0 0.75
C114 52.0 33.0 5.0 6.0 6.0 1.0 ** ** ** ** 0.75
C117 71.0 50.0 2.0 2.0 0.0 1.6 -1.34 -1.05 11.0 50.1 0.50
C12 59.0 59.0 5.0 2.0 2.0 5.0 -2.34 -3.10 1.0 20.0 0.50

Mean 46.3 50.8 3.6 3.3 2.2 16.5 -1.77 -1.82 14.0 31.2 0.69
SD 24.0 16.3 1.2 1.6 2.9 22.8 2.20 2.10 9.2 15.6 0.11

NH 2.43

*Speech measures, listening habits, musical background scores, length of deafness, cognitive measures, and recognition scores for cochlear implant (CI) recipients. Average recognition scores for normal-hearing (NH) participants are presented for comparison.

**Data not available.

tively weak (length of deafness, r = -.19, p = .34; musical background, r = -.03, p = .88). There was no significant correlation between the two dependent variables of recognition and appraisal.

Tertile rankings were also calculated for the recognition measure (Table 4). The most significant difference between the groups was for preimplant listening habits (p = .0001). Differences existed both between the high and low tertiles (p = .0001) and the middle and low tertiles (p = .0008). The only other significant difference was for the VMT in the one per 2-second rate (VMT2; p = .0078). This difference in visual monitoring was significant between the high and low tertile groups (p = .0105) and the middle and low tertile groups (p = .0432).
DISCUSSION

No significant differences were found between the two different pulse widths (75 μsec vs 150 μsec) for either appraisal or recognition. However, comparisons between implant recipients and normal-hearing listeners indicate that Clarion implant recipients find some instruments to be significantly less likable. Further, implant recipients are significantly less accurate in timbre recognition than are normal-hearing listeners. This finding is consistent with Schultz and Kerber's (1994) study comparing normal-hearing listeners with MED-EL recipients for recognition of four synthetic instrumental sounds. Although there are differences between the present study and that of Schultz and Kerber with regard to the stimuli and response format, both devices tested (Clarion and MED-EL) make use of a CIS processing strategy. Therefore, the similarity in outcome with regard to recognition is not especially surprising.

Recognition errors of normal-hearing listeners in the present study tended to be within the same instrumental family (e.g., confusing one string instrument, such as a violin, for another string instrument, the cello), while errors of the implant users tended to be more diffuse. A preliminary analysis (P Abbas, personal communication, 1997) of the output of the different implant channels for the four different stimuli suggests that the manner in which the device encodes the stimulus envelope may contribute to poorer recognition. Visual comparison of the amplitude of the pulses for each channel over time (onset transients and steady state of the first note, "C4" of each of the four instruments) indicates that there were differences in the output for each instrument that could contribute to global discrimination among the four sounds. However, the output over time did not reflect all of the details of the stimulus envelope. Thus, the device may not encode enough features of the stimulus envelope to make possible recognition or qualitative judgments similar to that of normal-hearing persons. It is also possible that the processing capability of the implant recipients' nervous system may be implicated in both accuracy and qualitative judgments. These hypotheses require further study.

The finding that the better performance on the VMT was associated with better performance on the timbre recognition task is interesting in that the VMT was also the better predictor of performance on speech recognition tasks by Nucleus and Ineraid implant users in earlier studies (Knuston et al, 1991; Gantz et al, 1993). The fact that speech recognition scores did not predict timbre recognition indicates that the success of the VMT in the present study is not merely a reflection of shared variance between the timbre recognition task and the speech recognition task. It is also interesting that the VMT was associated with the appraisal of the timbral stimuli. Taken together, the current findings and earlier studies of speech recognition suggest that the VMT might be assessing an attentional and information processing ability that is critical for a broad range of audiologic performance of CI recipients.

Several aspects of the present findings suggest that the perception of musical stimuli by implant recipients is not merely a reflection of a general audiologic capability largely redundant with speech perception. First, the lack of an association between the timbre recognition and appraisal scores and the speech perception scores indicates the lack of redundancy among the measures. Second, with the exception of the VMT, factors that have been shown to predict speech perception scores (e.g., sequence completion, duration of profound deafness) are not at all useful as predictors of timbral recognition and appraisal. Such findings underscore the possible importance of broadening the domain of tests that might be used to assess the ultimate outcome of the current generation of CI.

Whereas one might attribute poorer recognition, in part, to less exposure to or instruction about various musical instruments during the period of deafness (and consequently less knowledge of musical instruments and their sound characteristics), there were weak correlations between the accurate recognition of instruments and both the length of profound deafness and musical background. The significant correlation between recognition and preimplant listening habits (p = .005) suggests that persons with more extensive listening experience prior to hearing loss may be more successful in recognition tasks. The significant correlation between appraisal and postimplant listening habits (p < .008) suggests that quality of timbre may improve with more listening experience, or possibly that those persons receiving a more pleasant signal are most likely to spend time listening to music.

Although it is not essential to listening enjoyment that an individual be able to identify a particular instrument, a pleasurable response is of central importance in most music listening
experiences. It is therefore a positive finding that differences between normal-hearing listeners and Clarion implant recipients for appraisal were statistically significant for only some of the instruments sampled. However, it seems clear that technical modifications to the device intended to improve the quality of music listening would be beneficial for those individuals who wish to enjoy music listening, since these implant recipients do show a generally more restricted and lower range of appraisal and may therefore derive less musical pleasure than normal-hearing listeners.

While individual enjoyment of timbral quality is subjective in nature, these data indicate that normal-hearing listeners, as a group, make sharper distinctions from one instrument to the next with regard to appraisal, and also find some instruments to sound more pleasant than do Clarion implant recipients. These data are consistent with a prior study examining a different device type, the MED-EL implant (Schultz and Kerber, 1994). Additional research is needed to determine whether appraisal or recognition of timbre actually changes as a result of more particular types of listening experience and whether some timbral qualities are more likely to improve in pleasantness than others following more listening experience.

The qualitative judgment of musical sounds (appraisal) is a very important factor in musical enjoyment and therefore merits investigation. However, the subjective nature of this particular variable should be taken into account in analysis. For example, some of the implant recipients report that even an imperfect listening experience is preferable to silence and therefore may give more positive ratings to timbres that normal-hearing listeners would consider disappointing. In contrast, some of the implant recipients have described the sound quality as being so inferior to recollections of past listening experiences that they find little pleasure in music listening and thus show generally low appraisal responses.

To determine whether implant recipients tended to favor the sound of those instruments they correctly identified, measures of recognition were correlated with appraisal. Correlations were not significant. This may be explained, in part, by the fact that participants were not confident about the accuracy of their own responses.

Admittedly, the present study examines a very small sampling of the universe of possible musical timbres in a narrow frequency range (i.e., for the fundamental frequency of the pitch sequence) and in a relatively isolated and simple form. Music is a very complex and diverse auditory event, so it is no surprise that much remains unanswered with regard to musical perception of implant recipients. Future studies are needed to determine to what extent timbres are accurately perceived and enjoyed with various devices and coding strategies (with particular attention to the manner in which the device or strategy handles onset transients), including a larger variety of instruments representing a fuller frequency range, different forms of articulation, and in blended format (more than one instrument played simultaneously). Because music is such a pervasive environmental sound and social activity, improved satisfaction with music listening is a worthy outcome to strive for in the development of device upgrades and merits systematic assessment.

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