Tenth Quarterly Progress Report

July 1 through September 30, 2004
NIH Project N01-DC-2-1002

Speech Processors for Auditory Prostheses

Prepared by

Dewey Lawson, Blake Wilson

Robert Wolford, Xiaoan Sun, and Reinhold Schatzer

Center for Auditory Prosthesis Research
Research Triangle Institute
Research Triangle Park, NC

CONTENTS

I. Introduction

The main objective of this project is to design, develop, and evaluate speech processors for implantable auditory prostheses. Ideally, such processors will represent the information content of speech in a way that can be perceived and utilized by implant patients. An additional objective is to record responses of the auditory nerve to a variety of electrical stimuli in studies with patients. Results from such recordings can provide important information on the physiological function of the nerve, on an electrode-by-electrode basis, and can be used to evaluate the ability of speech processing strategies to produce desired spatial or temporal patterns of neural activity.

Work and activities in this quarter included:

- Initial studies with subject NP-7 (August 23-25), implanted with an experimental version of the Nucleus device that provides percutaneous access to a Contour electrode array. The studies included threshold and MCL determinations, pitch ranking, and initial consonant identification tests with clinical and research processors.
- Initial studies with subject NP-9 (August 14-16), also implanted with the experimental Nucleus percutaneous device. The studies included threshold and MCL determinations, pitch ranking, and initial consonant identification tests with clinical and research processors.
- A visit by Prof. Sung June Kim, Seoul National University, September 27

In addition to the above-mentioned activities, work continued on analyses of previously collected data and on the preparation of manuscripts for publication

In the present report we summarize pitch ranking data for all 22 of our bilaterally implanted subjects. Also included is a description of a melody recognition test system developed to allow control over more of the variables inherent in such testing.

Results from other studies, including those completed during the current quarter, will be presented in a future report.

II. Pitch ranking of electrodes for 22 subjects with bilateral implants

Our group now has studied a total of 22 subjects with bilateral cochlear implants. The studies have included investigations of sensitivity to interaural time and amplitude differences, and of reception of speech in competition with noise from various directions, using a wide variety of candidate stereophonic speech processing strategies. Other studies have assessed potential benefits of additional contralateral stimulation sites to the performance of monophonic processors.

Tables 1 and 2 summarize some attributes of our 22 subjects. Table 1 identifies each subject's bilateral cochlear implant devices, the number of electrodes available for stimulation on each side, the approximate number of years each subject went without bilateral stimulation, the number of years each went without any significant auditory stimulation, the month and year of each subject's most recent visit to RTI, and the total number of days each has served as a research subject at RTI. Table 2 lists what is known about the etiology of each subject's deafness.

Central to all our studies with this group of subjects has been a knowledge of differences and similarities in perceived pitch across all available stimulating electrodes. After initial determination of threshold and most comfortable loudness (MCL) stimulation levels for a pulse rate and duration to be used in psychophysical studies and with speech processors, the MCL levels across both sides are carefully loudness balanced in preparation for pitch ranking.

Three different techniques have been employed in obtaining pitch ranking data: (1) an initial informal ranking to obtain a putatitive list of electrodes in pitch order, (2) a formal matrix survey comparing randomized pairs of electrodes in a specified range within such a putatitive list, and (3) a sequential analysis of selected pairs, guided by a chart that embodies a statistical standard and terminated as soon as that standard is met.

Informal Ranking

Pulse bursts were played sequentially to pairs of electrodes at the loudness-balanced MCL levels to obtain an indication of pitch ranking of the percepts within and across the two arrays and to identify potential contralateral pitch-matched pairs for studies of other variables. The number of trials with each pair varied. The result was a list of both sides' electrodes in a putative pitch order and a list of potential pitch-matched pairs.

Matrix Method (Lawson *et al.* 1998)

A pair of loudness balanced MCL pulse bursts separated by 0.5 s were delivered to two different electrode sites. The subject was asked to indicate whether the second sound was higher or lower in pitch (two alternative forced choice). Initially, each comparison was for electrodes separated by a fixed, relatively large distance, specified by an initial offset in position along the putative list. After a specified number of randomized comparisons of each pair of electrodes sharing that

Table 1.

Subject	Devices	Avail. Els		Duration (yrs)		Studies at RTI	
		L	R	no bilat.	no stim.	Last Visit	Tot. Days
NU4	N22	16	8	1	0	12/01	37
NU5	CI24M	20	20	0	0	3/99	9
NU6	CI24M	22	20	2	1	6/02	19
NU7	CI24M	22	22	20	6	3/02	20
NU8	CI24M	20	19	0	0	11/00	10
ME2	C40C	8	8	3	2	10/97	15
ME3	C40P	12	12	5	2	8/03	20
ME4	C40P	12	12	2	2	7/00	13
ME5	C40P	12	12	3	2	8/00	15
ME7	C40P	9	12	0	0	9/01	14
ME8	C40CS, C40P	8	11	9	3	1/01	14
ME9	C40C	7	8	32	0	3/01	10
ME10	C40P, C40C	12	8	31	11	9/03	30
ME12	C40P	12	12	2	1	6/03	17
ME14	C40P	12	12	6	0	10/03	11
ME15	C40P	11	11	13	0	7/03	25
ME16	C40P	12	12	10	0	12/03	23
ME17	C40P	12	12	12	0	9/02	5
ME18	C40P	12	12	20	0	5/03	18
ME21	C40P	12	12	0	0	2/03	7
ME22	C40P	12	11	0	0	6/03	4
ME24	C40P	11	12	0	0	1/04	2

Table 2.

Subject	Etiology of deafness
NU4	Listeria rhomboencephalitis
NU5	acute noise exposure, further loss during subsequent pregnancy
NU6	onset coincident with poliomyel(oencephal)itis, familial history
NU7	Méniere’s disease
NU8	Méniere’s disease
ME2	gradual progressive
ME3	sudden loss of unknown cause
ME4	bilateral basal skull fractures
ME5	otosclerosis
ME7	bilateral temporal bone fractures
ME8	Méniere’s disease
ME9	measles, familial history
ME10	right skull fracture, later sudden and progressive losses
ME12	20 years noise exposure as military pilot, familial history
ME14	genetic
ME15	sudden onset, each side separately
ME16	unknown, sudden, familial history
ME17	Méniere’s disease
ME18	noise exposure, familial history
ME21	meningitis
ME22	early, likely genetic
ME24	left head trauma, progressive, familial history

separation (equal number of presentations of each pair in each order), the separation within the putative list was reduced by one and the process repeated. Thus a subject typically would experience clear pitch contrasts early in the test, gradually becoming more subtle. The percentage of responses consistent with putative list order could then be displayed in a matrix of absolute electrode position *vs.* offset within the list. Based on early comparisons, rearrangement of the list could be followed by additional comparisons, eventually resulting in a map of pitch discrimination across the electrode array against which various proposed subsets of electrodes could be considered for assignment to processor channels, or for use in psychophysical studies.

Sequential Analysis (Lawson *et al.* 2001)

Based on earlier work on sequential analysis (Wald 1947), model procedures were developed for determining that two conditions are discriminable or indiscriminable under selected statistical criteria (Bross 1952). The procedures, embodied in graphic charts for recording the results of successive trials with randomized presentation order, were designed to be terminated as soon as the statistical criteria are met, rather than requiring a fixed number of trials in each case. Plan A as presented in Bross' paper – designed to ensure a correct determination of discriminability 90% of the time – was selected for use in formal pitch ranking determinations by our lab. The associated chart and a discussion of its use have been presented in a prior QPR (Lawson *et al.* 2001a).

The statistical criteria contained within this sequential analysis procedure require a minimum of seven trials with each stimulus pair. Seven trials are sufficient only if the subject identifies the same stimulus as being higher in pitch in every case. Similarly, agreement in 9 out of 10 trials (90%) meets the statistical criterion for discrimination, and the minimum required percentage drops slowly as the number of trials increases (72% is sufficient after 25 trials, 66% after 35 trials, 60.4% after 48 trials). On the other hand, a minimum of 22 trials (divided at 50% with 11 instances of each response) is required to establish that two stimuli are statistically indistinguishable, and the maximum percentage consistent with that verdict increases slowly after more trials, *e.g.* 58.3% after 48 trials. In our practice, several different electrode pairs are evaluated as a group, with separate charts for each pair and the order of successive trials randomized among the pairs. These statistical criteria are summarized in Figure 1.

Sequential analysis has particular advantages when the task is to identify pairs that are indistinguishable on the basis of pitch. Some candidate pairs can be eliminated after only 7 – 10 trials, for instance. And the more thorough exploration required to conclude that a pair are truly pitch matched is built into the procedure. Once a limited number of such pairs had been identified in a subject using sequential analysis, relatively little further effort would be required to extend the number of trials and reduce the roughly 10% chance of error remaining inherent in Bross' Plan A chart.

An extended matrix procedure may be superior to sequential analysis, however, for identifying electrodes to support independent channels of stimulation for speech processors. While a contralateral pair of electrodes determined to be rankable on the basis of pitch with a 61% score after 48 trials has passed the same statistical test as a pair ranked the same way on all of an initial 7 seven trials or 9 of an initial 10, such a pair would not necessarily support independent

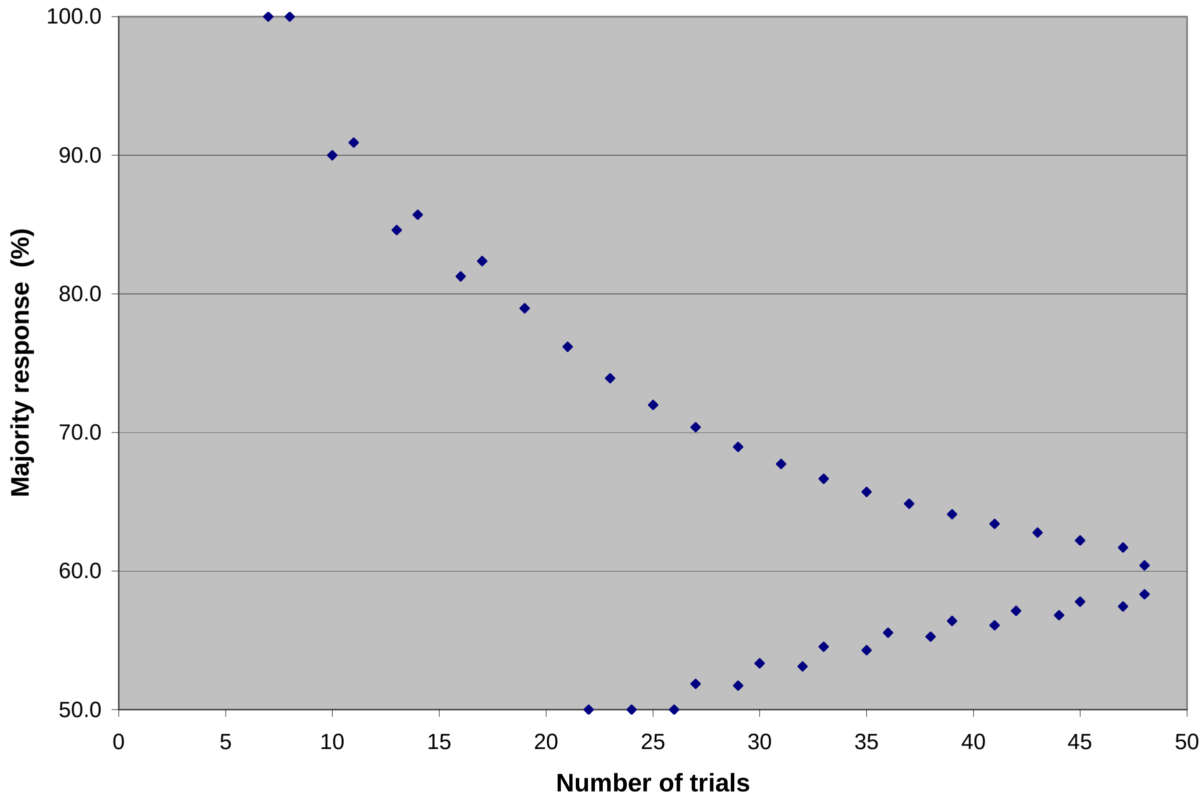


Figure 1. Criteria for discriminability between two alternatives, expressed as percentage of the majority response as a function of the number of trials. The upper group of points indicates the minimum percentage to determine discriminability after a given number of trials (a minimum of 7 trials are required for such a determination). The lower group of points indicates the maximum percentage of responses for one alternative consistent with a determination of indiscriminability after a given number of trials (a minimum of 22 trials are required for such a determination). Values derived from the Plan A chart (Bross 1952).

channels as well as a pair that, say, maintained a 90% ranking score consistently through many more trials.

Alternative sequential analysis designs (*e.g.* Armitage 1957) may offer some advantages for future use.

In all three pitch ranking procedures, 300 ms bursts of pulses were presented, at rates and phase durations appropriate to the speech processing strategies used by each subject. The interval between bursts in a pair comparison was set at 500 ms in the automated matrix procedure and was approximately the same under manual control in the other two procedures.

Results

Our pitch ranking data for all 22 bilaterally implanted subjects are summarized in Figure 2.

Rankings shown in red (NU6, NU7, ME7, ME9, ME10, ME12, ME15, ME16, ME17, ME18, and ME21) are based on sequential analysis. In the case of some subjects, matrix studies preceded the sequential ones and data from those studies have been used where available to improve our judgments as to the ability of electrode pairs to support independent channels.

Rankings shown in blue (NU4, NU5, NU8, ME2, ME3, ME4, ME5, and ME8) are based on matrix comparisons, typically involving 10 to 20 comparisons of each regional pair. Further testing with sequential analysis might well indicate significant pitch distinctions between additional pairs but, as discussed above, might not represent the availability of additional independent channels of stimulation. The matched pairs indicated in these rankings may not be as well established as those using the sequential technique.

Rankings shown in black (ME14, ME22, and ME24) are based on initial, informal comparisons and/or relatively few comparisons within a matrix algorithm. They should be regarded as preliminary indications.

Side-by-side pitch-matched pairs displayed with white numbers on a red or blue background are those used by us in formal studies such as interaural time delay and interaural amplitude difference detection.

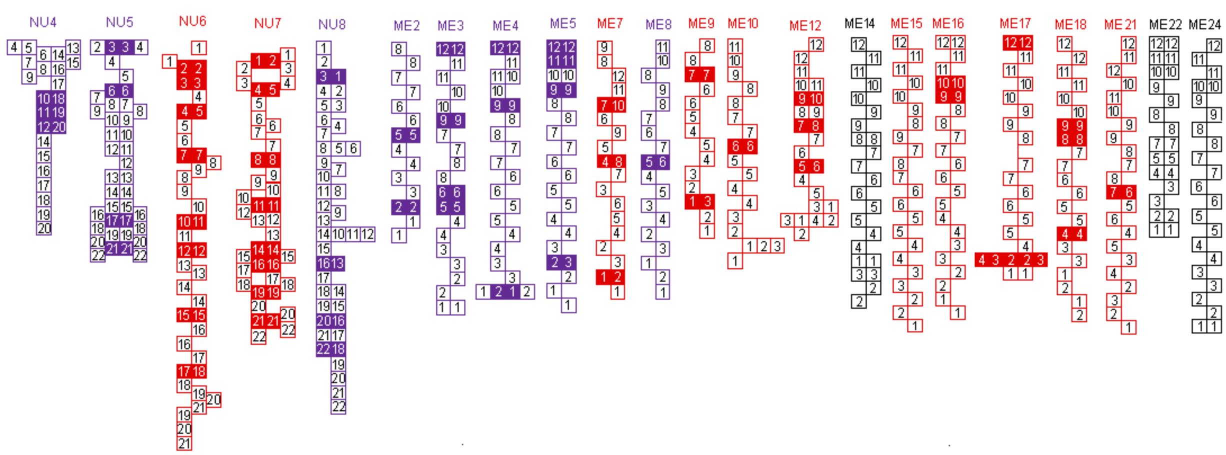


Figure 2. Pitch Ranking Data for all 22 bilaterally implanted subjects. Subject identification codes are at the top of each pair of columns, a NU prefix indicates a subject with bilateral Nucleus devices and a ME prefix a subject with bilateral Med-El devices. See Table 1 for specific devices. Each cell corresponds to a ranked electrode, with numbering from the basal end of the array for Nucleus devices and from the apical end for Med-El devices: in each case, electrodes associated with the highest pitch percepts are shown at the top of the figure. Within the pair of columns for each subject, the left side corresponds to the left ear. Only relative pitch ranking is conveyed: no significance should be attached to the degree of vertical displacement or overall vertical extents. Cells shown side by side for the same subject could not be discriminated on the basis of pitch. The vertical extent of each pair of columns indicates the number of pitch-distinct stimulation sites for that subject. Data represented in red were obtained using a sequential analysis approach, those shown in blue were obtained using a matrix comparison approach, and those shown in black represent preliminary informal assessments. Each method is described in the text.

A number of patterns that emerge in Figure 2 have implications for research possibilities and clinical expectations.

Pitch ranking patterns and apparent relative insertion depths are generally quite similar across sides in the same subject, even for ME8 where a shorter higher-density array was implanted on one side. A possible exception is the case of ME10, also involving different implanted electrode arrays on the two sides. For NU4, the electrode array on one side was inserted only about half way due to obstruction in scala tympani.

The data for NU6 and NU7 provide examples of a wealth of contralateral pitch-matched pairs at various locations across the cochleae of a single subject. Such subjects are particularly valuable for such studies as interaural amplitude difference and interaural time delay detection, as well as for studying binaural speech processing strategies with channels of stimulation that are pitch-matched on the two sides.

In ME15 we have a subject all of whose electrodes are pitch discriminable, within and between implants, potentially supporting twice as many independent channels of stimulation as the number of electrodes on either side alone.

Pitch ranking results for many of our subjects indicate tonotopic consistency along each electrode array – *e.g.* ME2, ME5, ME15, and ME16. In other cases (*e.g.* ME3, ME14) occasional marked tonotopic inconsistencies were observed.

The results for some subjects show regions of relatively poor pitch discrimination across electrodes – *e.g.* NU4, NU5, ME17, and ME12, perhaps reflecting regions of relatively poor neural survival, or distant placements of the electrodes with respect to excitable tissue.

Table 3 indicates the number of pitch-distinct channels of stimulation available for each subject – on each side alone and with both sides considered together. These data are based on the pitch rankings of Figure 2, and may be influenced to some extent by differences among the techniques used to obtain those rankings. Rankings obtained with sequential analysis, for instance, may tend to indicate additional significant distinctions beyond those based on matrix comparisons.

The average bilateral channel advantage – defined as the number of pitch discriminable channels available across both sides divided by the maximum number of pitch discriminable channels available on one side in the same subject – has average and median values of about 1.6 across the 17 ME subjects. This provides some indication of the potential clinical benefits of additional independent stimulation channels for monophonic speech processor use.

Among the 11 cases investigated with sequential analysis, the ratio of the number of contralateral pitch-matched electrode pairs at distinct pitches to the lesser of the numbers of electrodes available on each side provides some indication of the incidence of such opportunities for psychophysical comparisons controlled for pitch. The average of that ratio for these 11 subjects is 0.24. It is 0.38 for the two NU subjects and 0.18 for the nine ME subjects.

Table 3.

Subject	Devices	Pitch-Discriminable Channels			
		Left	Right	Both	Advantage
NU4	N22	13	6	13	1.00
NU5	CI24M	13	14	15	1.15
NU6	CI24M	20	18	28	1.40
NU7	CI24M	15	17	20	1.18
NU8	CI24M	22	19	26	1.18
ME2	C40C	8	7	13	1.63
ME3	C40P	12	12	19	1.58
ME4	C40P	11	11	18	1.63
ME5	C40P	12	12	19	1.58
ME7	C40P	9	10	16	1.60
ME8	C40CS, C40P	8	11	18	1.64
ME9	C40C	7	8	12	1.50
ME10	C40P, C40C	11	6	16	1.45
ME12	C40P	11	10	15	1.36
ME14	C40P	12	11	20	1.60
ME15	C40P	11	11	22	2.0
ME16	C40P	12	12	21	1.75
ME17	C40P	9	11	17	1.55
ME18	C40P	12	12	21	1.75
ME21	C40P	11	12	22	1.83
ME22	C40P	11	11	14	1.27
ME24	C40P	11	12	21	1.75

Discussion

Searches for pitch-matched pairs of electrodes can be made more efficient through the use of sequential analysis procedures, allowing the elimination of some candidates after only 7-10 trials. Additional testing of those pairs identified as pitch indiscriminable by sequential analysis on the basis of relatively few trials (*e.g.* 22) can further improve the 90% accuracy of the technique's determinations.

Those pairs of electrodes determined by sequential analysis to be pitch discriminable only after many trials (*e.g.* 45) are not likely to be good choices to support independent channels in a speech processor. Among the pairs determined to be discriminable on the basis of 90% or better scores after only 7 to 10 trials, there may be some that would continue to yield such high scores through more extensive testing. Such pairs might be good choices to support highly independent channels in a processor, and the further testing required to identify them should be considered.

In some circumstances – such as a simultaneous need to identify both pitch-matched pairs for research and sets of pitch-distinct electrodes for independent processor channels – the additional testing described in the previous two paragraphs may effectively cancel any efficiency gained through the use of a sequential technique rather than an extended matrix survey.

III. References

Armitage P. (1957) "Restricted Sequential Procedures." *Biometrika* **44**: 9-26.

Bross I. (1952) "Sequential Medical Plans." *Biometrics* **8**, 188-205.

Wald A. (1947) *Sequential Analysis*, John Wiley and Sons, New York (pp. 106-116).

Lawson DT, Wolford RD, Brill S, Schatzer R, and Wilson BS (2001) "Further studies regarding benefits of binaural cochlear implants." QPR 12 for NIH Project N01-DC-8-2105.

Lawson DT, Zerbi M, and Wilson BS (1998) "Pitch discrimination among electrodes and interaural timing and amplitude cues in three subjects with bilateral cochlear implants." QPR 1 for NIH Project N01-DC-8-2105.

IV. Melody recognition tests for cochlear implant research

A number of researchers have conducted studies related to music perception by cochlear implant users. (*e.g.* Dorman *et al.* 1991; Fearn 2001; Gfeller *et al.* 1991, 1997, 2002, 2003; Kong *et al.* 2004) It has been shown that, while some important attributes of music – such as rhythmic structure – are quite accessible to the typical user of current cochlear implants and processors, others – notably pitch and spectral detail – are not. (An often noted fondness for and recognition of piano "timbre" by cochlear implant subjects is most likely due to the characteristic envelope of a hammered string sound, since even experienced pianists with normal hearing generally don't recognize a sustained piano note among recordings of various instruments played backwards, preserving fine spectral cues.)

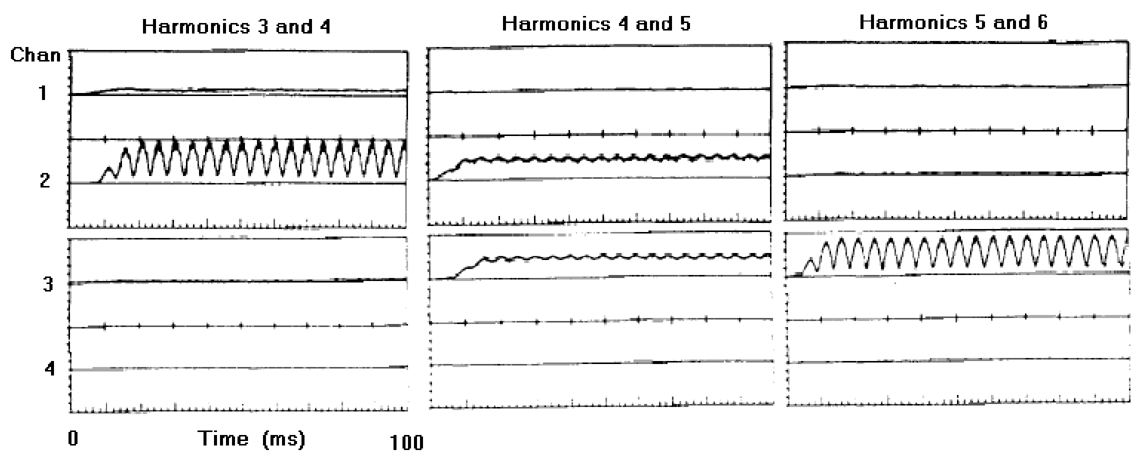
Many studies have involved assessing subjects' pitch perception ability as evidenced by recognition of familiar melodies. Typically, rhythmic cues are largely removed for such tests, leaving sequences of identical numbers of notes of identical duration presented at identical rates. The notes for these and other tests often have been obtained from the synthesized tones available on commercial MIDI electronic instruments or from digitally sampled recordings of acoustic instruments. Such choices have left many potentially significant variables uncontrolled, including spectral content of the instrument sounds, note-to-note variations in loudness and timbre, and differing responses of the cochlear implant processor to notes in the same melody when transposed to a different set of fundamental pitches. The potential significance of many such variations was demonstrated in earlier pilot studies in our laboratory (Lawson *et al.* 1993, 1994). Recent work indicates that covariance of pitch and timbre can complicate even normal listeners' ability to distinguish among musical instruments (Handel and Erickson 2004).

We have developed an extensive set of tools to conduct studies of patterns in complex tone perception and melody recognition with various cochlear implant strategies, all with detailed control of stimulus design and interactions with individual subjects' processor parameters. We recently have conducted pilot studies of melody recognition tests that include such controls, using sets of melodies familiar to American, German, and Polish subjects.

Individual musical tones typically are composed of a harmonic series of pure tone partials, or a subset of such a series – with frequencies that are integer multiples of some fundamental frequency (which may or may not be present itself). Simultaneously played pairs of notes superimpose two such harmonic series, with some common ratio (corresponding to a musical interval) between their fundamental frequencies, leading to more closely spaced partials in the combined musical sound. Musical chords superimpose three or more such complex tones, with still more closely spaced partials.

When such a musical sound is analyzed by a cochlear implant processor, its partials effectively will be sorted among the channels, according to the frequency ranges of the analysis bands. Each partial will either affect the analysis of a single band, if its frequency lies well within the band, or both of an adjacent pair of bands, if it lies near a band edge. Multiple partials within the same band will interact (beat) and can result in temporal fine structure at their difference frequency (the fundamental in the case of adjacent harmonics), which may be reflected in the channel's envelope and, thus the varying amplitude of its output pulse stream.

In the plots below, the sounding of three successive pairs of adjacent harmonics of the same fundamental produce quite different effects in processor output, because harmonics 3 and 4 both fall into the analysis band of channel 2, while harmonics 5 and 6 both fall into the analysis band of channel 3. Thus the combination of harmonics 3 and 4 produce a strong modulation at the fundamental frequency in the envelope of channel 2, and the same is true for the combination of harmonics 5 and 6 and channel 3. The ostensibly equivalent combination of harmonics 4 and 5, however, produces amplitudes in both channels, but -- because of the relatively high harmonic frequencies and the channel's envelope smoothing filter cutoff -- little modulation in either.



Channel Envelopes for Three Pairs of Adjacent Harmonics

Even small transpositions of such complex musical sounds (altering the frequencies of all the partials by a common factor – a common musical interval) can produce large changes in the distribution of partials among the analysis bands. Successive transpositions by the same small interval may produce only subtle differences within channels in one case, but a profound redistribution among channels in another.

In order to study how musical information may be conveyed by such processing strategies, then, it is important to consider potential cues produced by differences both within and across channels, and both in terms of relative overall channel amplitudes (spectral information through place of stimulation) and the temporal structure of individual channel envelopes.

For the melody tests developed for use in our laboratory, a master set of melodies likely to be familiar to a post-linguistically deafened adult has been assembled for each of three native languages – English, German, and Polish. Many of the melodies are children's songs, holiday songs, patriotic songs, and folk songs. A 16-note sequence is available for each melody, for presentation at fixed note duration and tempo. While such presentations are designed to remove rhythmic cues from the melodies, in some cases the 16 notes in a sequence will include repetitions of the same pitch corresponding to prolonged single notes, arguably conveying some rhythmic information to subjects who can discriminate between successive notes that are the same or different in pitch. Each 16-note melody is transcribed as a sequence of non-negative integers, including at least one zero, representing relative musical pitch in semitones ("half steps"). Thus all the melodies, as transcribed, share the same lowest pitch, but that pitch occurs at different places in different melodies.

Each subject is shown a list of labels for the master set corresponding to his or her native language. The labels are a mixture of titles, beginning phrases, and other common identifiers as appropriate for each melody. The subject is asked to mark those melodies that s/he is familiar with and can recall. From the items thus marked, one or more lists of melodies are constructed for use in melody recognition tests with that subject. Typically, each list contains twelve melodies. Each such subject-specific list is contained in a file **XXmelNN.txt**, where XX is a code identifying the subject, and NN a serial integer distinguishing among the various lists. Such a file contains three lines per melody: the melody title or other label for display to the subject, a 3-character abbreviation for labeling matrices, and the comma-delimited sequence of 16 semitone offsets defining the melody.

Single values of some of the controlled variables are specified for each test (pitch range, spectral content of each note, list of melodies, processing strategy), while three different transpositions are included within each test.

To achieve the necessary level of control over complex tone stimuli, several years ago we developed a software synthesizer, analysis tool, and test administrator called **MusiCI** (pronounced "MOO-see-chee" as in the Italian word for musicians). (Lawson 2000) As a synthesizer, MusiCI uses a file containing a detailed characterization of each individual processor's analysis band design to identify partials whose amplitudes will be at least 20 dB down in any adjacent channel or, less selectively, at least 10 dB down. This allows the avoidance of a single partial's affecting analysis in two separate channels and can be used, for instance, to include pairs of adjacent partials only if they are associated unambiguously with the same analysis channel. MusiCI produces waveform files and can play them through a computer's audio outputs. Waveforms can be constructed with partials consisting of any combination of harmonics of a single fundamental, or of pairs of fundamentals separated by a musical interval, or of three fundamentals separated by musical intervals. [The frequency of the lowest fundamental is selected from an equal tempered scale. Just intonation is used for perfect fifths and fourths and major and minor thirds and sixths separating upper fundamentals from the lowest one, with equal temperament used for the less consonant intervals.] Any two synthesized tones or combination of tones may be stored at the same time and viewed and played rapidly on command for comparison. Two-octave chromatic scales of tones either containing the same harmonics or harmonics chosen under the same selection rules can be constructed and stored as well. Notes from such stored scales can be played rapidly within the MusiCI program itself, using a mouse to select pitches from a graphic musical keyboard, or can be employed in automated melody recognition tests such as the ones presently under discussion.

[We recently developed an extension of this utility – called **CIMusiCI –** which can produce distinct left and right ear audio outputs as part of a stereophonic signal, taking into account detailed characterizations of the processor analysis bands associated with both sides of a binaural pair of cochlear implants. As an analysis tool, MusiCI and CIMusiCI can display a number of plots and tables relating the interactions among adjacent pairs of partials to normal hearing perceptual classes (Lawson 1980) and to parameters relevant to the cochlear implant processor. As a test administrator, the utilities can use a script file supplied by a researcher to synthesize test tones, play them, display any of a wide range of options for subject responses, and record the responses in another file for return to the researcher for analysis. (Lawson 2000)]

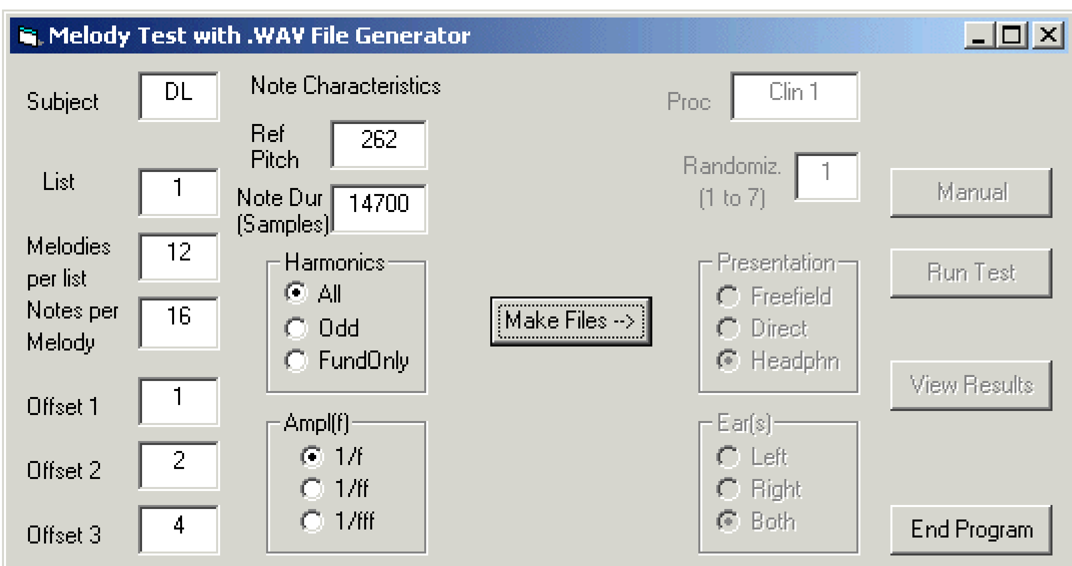
Even if a generic set of stimulus tones is desired – without any controls for the analysis bands of a particular processor – MusiCI provides a very convenient way to synthesize them. The set of files containing the two octave range of synthesized tones will be named not1.wav through not25.wav. That set, the subject-specific melody list file(s), and other resources are used by the utility program **melWAV.exe** to construct melody waveform files and conduct and archive the results of recognition tests. One additional resource needed by the melWAV program is a **noteparams.txt** file that is placed in the same folder with the synthesized note files and describes some of their important attributes. An example follows:

noteparams.txt

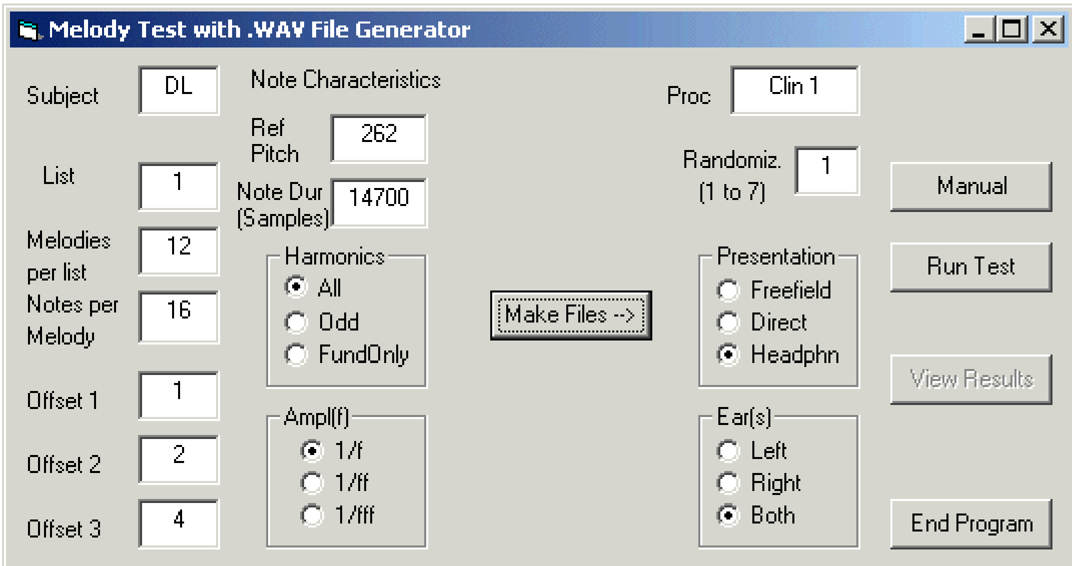
```
14700
262
A
1
```

In this example, the number of samples (at 44.1 ks/s) that define the duration of each note is 14700, the lowest fundamental pitch of the two-octave range of notes is 262 Hz, the spectral construction of each note includes All harmonics (of the first nine, as opposed to Odd harmonics or Fundamental only), and the relative amplitudes of the harmonics are inversely proportional to their frequencies (the first power of f, rather than its square or cube).

Those parameters are displayed in the second column of melWAV's initial window, under "Note Characteristics" as illustrated below.



Parameters in the first column of that window can be entered manually before clicking on the "Make Files" button to prepare a set of melodies for recognition tests. The "Melodies per List" and "Notes per Melody" default to the standard values shown, but have been made adjustable at this point in anticipation of possible future needs. The Subject code and melody List number entered here will be combined to form the name of the appropriate melody list file. Finally the three Offsets specify the lowest pitches (in semitones) in each of the three transpositions to be included in the test. In this example the pitches specified as zero in the melody list will, in the transpositions, be assigned to the 1st, 2nd, and 4th semitones of the available note set, respectively, making the second and third transpositions a musical minor second and minor third higher than the first.



Once the “Make Files” button is clicked on and the right half of the initial window becomes active, a set of 36 **melMMNNKO.wav** files will have been created, where MM indicates the number of notes per melody (at present a standard16), NN the melody number (determined by the order of the individual melody list, 01-12), K the transposition number (1, 2, or 3), and O an indication of the direction of included noise (0 indicates a quiet background; R, L, and F would indicate noise from right, left, and front, respectively). Their common parameters will be summarized in a **melparams.txt** file, as illustrated below.

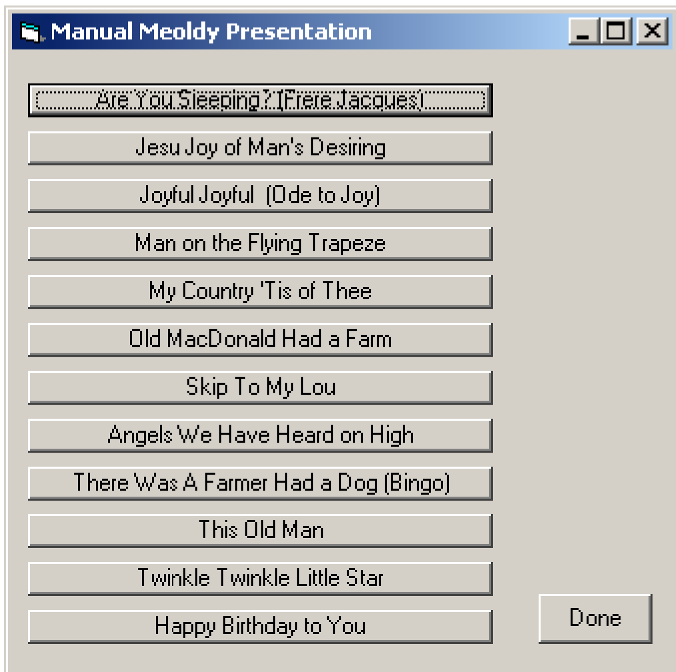
melparams.txt

```
14700
0262
A
1
DL
01
1
2
4
12
3
```

The first four lines of this file come directly from the noteparams.txt file describing the individual note files used. The final seven convey the subject identification code, the melody list number for that subject, the pitch offset for transposition 1, the pitch offset for transposition 2, the pitch offset for transposition 3, the number of melodies in the list, and the number of transpositions of each melody.

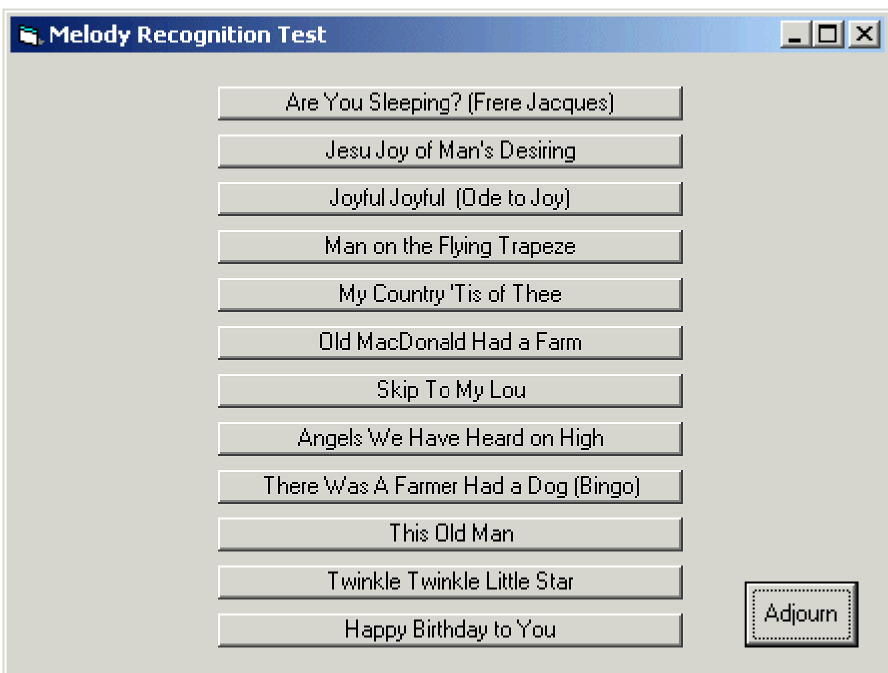
At this point, four parameters related to an individual test can be entered. The only one that actually affects the test is the Randomization number R for the randomization file name in the set **randR.txt**. Each randomization file contains one line per presentation, a three-digit number whose first two digits define the melody number and the third defines the transposition. The other three parameters are supplied at this point to be included in the archival record of the next test: identification of the processor being used, the presentation mode, and which ear(s) will be involved.

The “Manual” button can be used to verify most comfortable loudness and/or to allow the subject to familiarize her/himself with the list. It causes the following window to replace the initial one, allowing the melodies to be played in any order by clicking on the buttons containing their title or other identifier. When the “Done” button is clicked on, this window disappears and is replaced by the former (initial) one.



Another option at this point is to click on the “Run Test” button, which administers a melody recognition test using the last constructed melody set and the last specified randomization. In that event, the following window replaces the initial one.

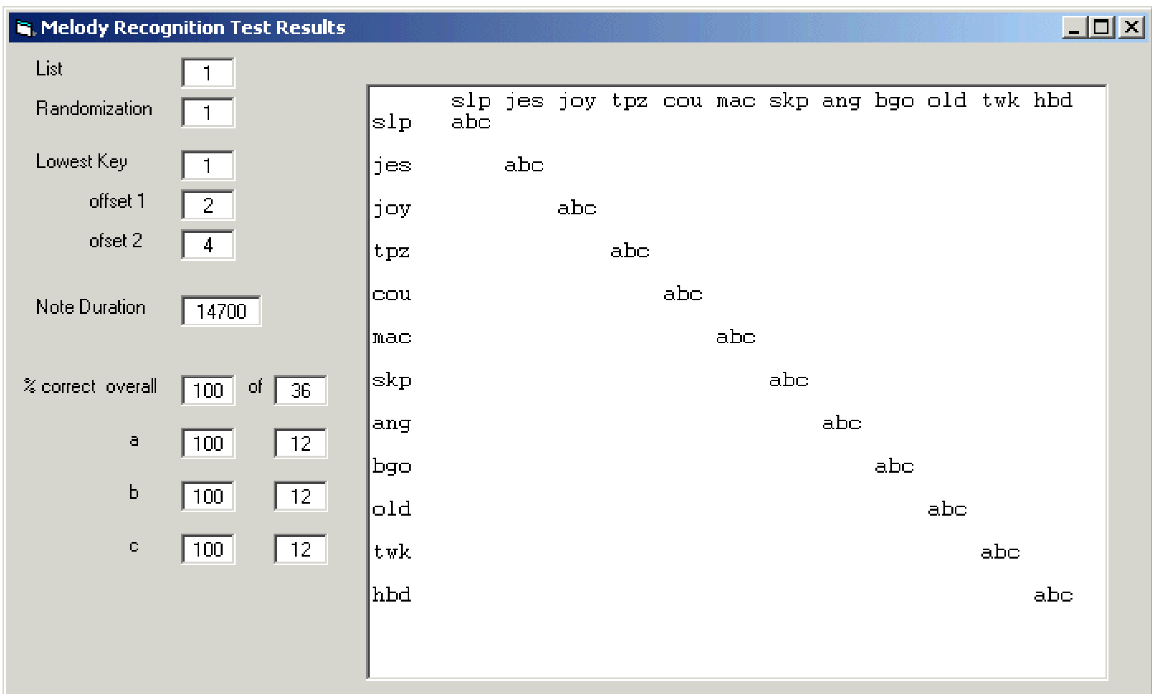
When the subject is ready to begin the test s/he clicks on the "Begin" button, which then disappears as the first (randomized) melody is played, and the twelve answer buttons are activated.



As the subject clicks on a button to identify the previously played melody, the next of the random sequence is automatically played. Each melody is presented three times during the test, once in each of the three specified pitch transpositions. The initial window automatically replaces this one when the test is completed, or when the "Adjourn" button is invoked.

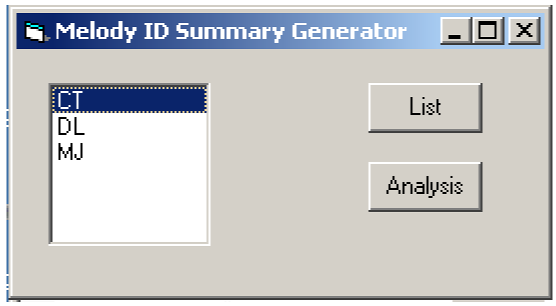
After each test, an entry is made to the subject's melody data archive file **XXmellog.txt**, where XX is the subject's identification code. Two lines are entered into that file for each test. The first line records the date and time of the test, identifications of the subject and the processor being used, and all the parameters included in the melparams.txt file for the test. The second line contains the melody number of each response, in sequence.

Once a test has occurred, the "View Results" button is activated in the initial window. Clicking on that button brings up the window shown below.

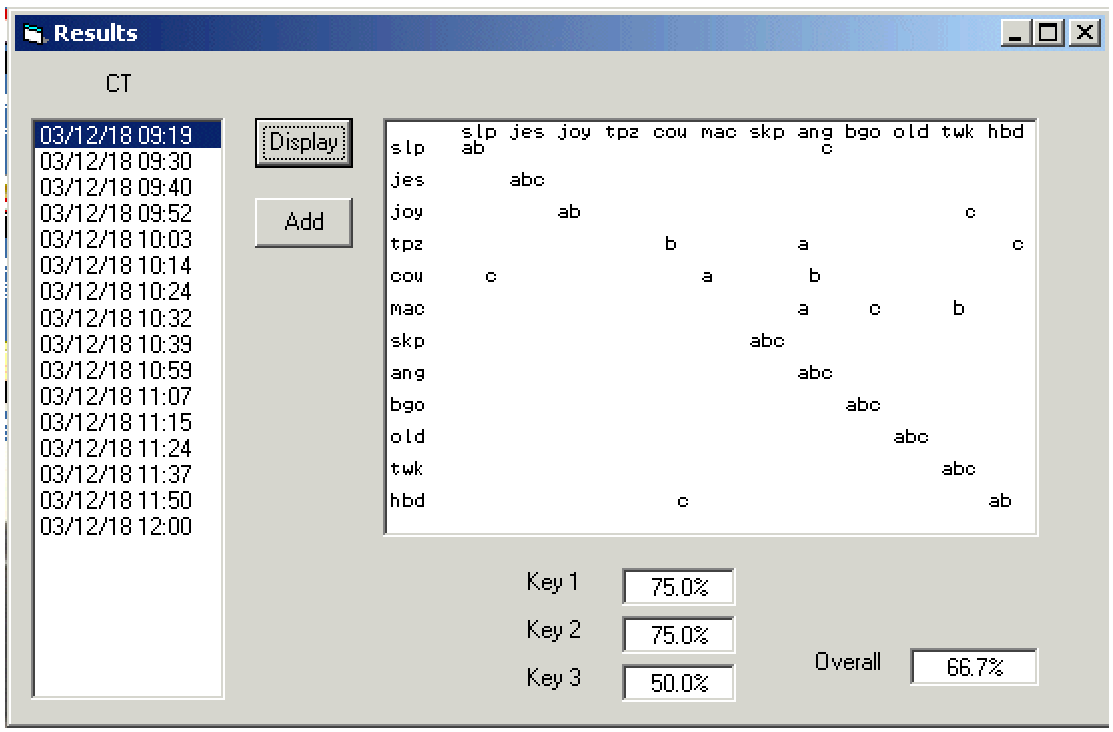


Test parameters are shown at the upper left. At the lower left are the overall percent correct identification score for the test and individual scores for each of the three transpositions of the same set of melodies, here labeled a, b, and c. In the confusion matrix at the right, three-letter abbreviations for the melodies (from the melody list file) label the rows (presented melody) and columns (response), and responses for the three different transpositions are marked with the characters a, b, and c. Information available at a glance, then, includes overall performance, presence or absence of consistency across transpositions, patterns of problems with certain melodies across transpositions, and patterns of problems with certain transpositions across melodies.

A separate utility program, **melANAL.exe**, allows combination of multiple melody identification tests for analysis, and display of such combined data. Its introductory window displays all subject identification codes for which melody recognition data exist.



Once a subject is selected by highlighting the appropriate code, the "List" button allows a detailed text file to be created in that subject's data archive folder, based on XXmellog.txt but expanded into a much more readable form. The "Analysis" button opens a Results window for the selected subject.

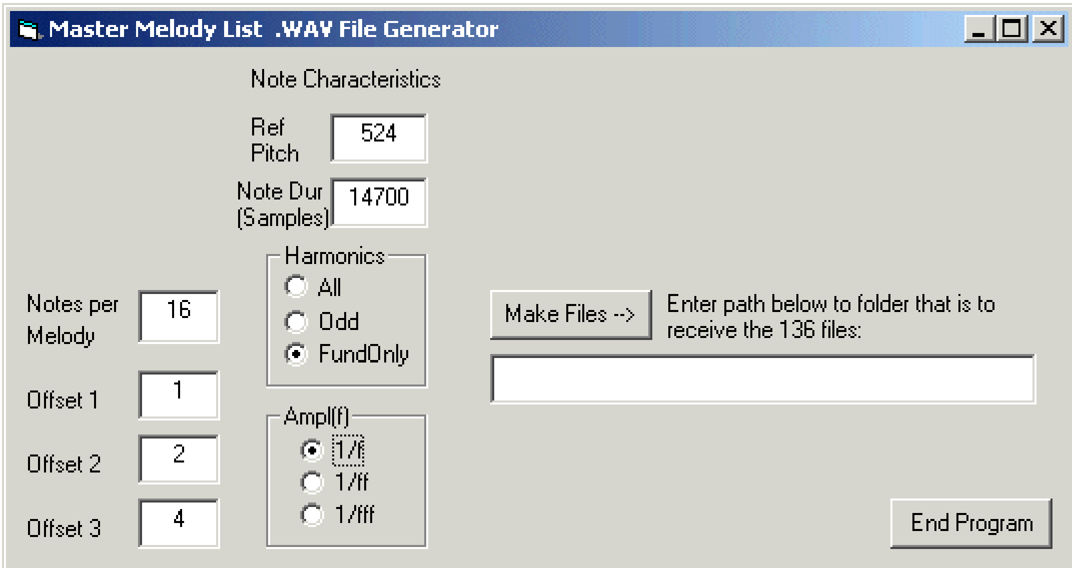


In the example above, the test with the earliest date-time stamp has been selected and the "Display" button clicked on, resulting in a display like that originally produced by melWAV at the conclusion of that test. In this case errors were concentrated in the melodies "Man on the Flying Trapeze" (tpz), "My Country 'Tis of Thee" (cou), and "Old MacDonald Had a Farm" (mac); and in the third transposition or "Key" (c, in this case three semitones above the first and two semitones above the second).

Additional tests could then be selected and their results combined with those already displayed by clicking on the "Add" button. While the positions of the a, b, and c subdivisions of each confusion cell would be maintained, the three characters would be replaced by integers tallying the total of the combined responses for each transposition. If the combined tests included different melody lists, reference pitches, or transpositions, appropriate warning messages would appear above the confusion matrix display.

The program melWAV allows immediate preparation of .WAV files and presentation of a melody recognition test by playing those files to the audio input(s) of a sound processor running in real time.

Another utility, **MastListWAV.exe**, allows automatic construction of .WAV files for three transpositions and for the entire master list of American English melodies. It's control window is shown below.



This utility is designed to support streaming mode testing, involving processing strategies that are implemented offline rather than in real time. (Schatzer *et al.* 2003).

Among our earliest experiences using these new, more controlled, multi-transposition melody recognition tests were studies with subjects whose scores ranged from chance to 100%.

The highest performance to date has been by subject ME-16, who uses Med-El TEMPO+ cochlear implant systems bilaterally. Clinically, she is fitted with 12-channel CIS processors, delivering pulses at a rate of about 1000 p/s/channel on each side, with various pulse durations for each channel, ranging from 26.7 to 60.0 µs/phase. The cause of her hearing loss, first diagnosed in 1991 at age 30 as a bilateral high frequency loss, is unknown. Sudden profound losses occurred at and above 2 kHz in the left ear in 1992 and the right in 1994, progressing to lower frequencies on both sides over the following years. Bilateral hearing aids were used from 1993 until bilateral cochlear implantation at the University of North Carolina Hospitals in June 2002. She began participating in research studies in our laboratory two months after implantation. She is musically astute.

In late 2003 ME-16 participated in pilot studies of our closed-set melody recognition tests, using two of her three clinical maps running on BTE external processors, with stimulus sounds presented via circumaural headphones. Given a list of titles and/or first line lyrics of well-known melodies, she marked those familiar to her. Two multiple choice lists of 12 melodies were constructed from that subset. Each test consisted of randomized presentations of the first 16 notes of each melody from one of those lists at each of 3 different pitch offsets (transpositions), with at least two tests typically administered in each condition. The three offsets were 0, +2, and +4 semitones (musically a unison, a major second, and a major third) with respect to a 131 Hz lowest fundamental pitch shared by each melody or, in other tests, the same three offsets an octave higher. Three sets of MusiCI-synthesized stimulus tones for each note were used: with the first nine harmonics, with odd harmonics only, and with the fundamentals only. All notes were of identical length (0.33 s) and were played at the same rate (tempo) of 3/s (M. M. 180).

In summary, individual melodies and transpositions by a major third or less were varied within each test, while test conditions involved differences in processing strategy, the spectral structure of each musical tone, gross frequency range (octave), and melody list.

ME-16's performance on these melody recognition pilot study tests was extraordinarily good – better than one might think possible based on a comparison of CIS processor limitations with the best current understanding of normal hearing processes. (Moore 2003) Her scores ranged from 44 to 100% (A chance score being 8.3% for the 12-melody closed set, a level not exceeded by some of the other subjects involved in the pilot studies.). In all conditions with tones containing either odd harmonics or all harmonics, she was able to attain scores of 90% or more with practice, and a similar level of performance was achieved for fundamentals only presented in the higher octave (In the lower octave conditions, some of the fundamentals were below the 250 or 300 Hz lower limit of the clinical processor's lowest analysis band.) Clearly, while these tests are amply difficult for many cochlear implant users, more difficult tests will be required to assess differences in ME-16's asymptotic performance levels across conditions. Equally clearly, a successful controlled search for the cues supporting such high performance that are conveyed by her cochlear implants could significantly inform attempts to improve pitch recognition by other implant users.

Strong patterns of errors were observed early in the subject's learning period for many of the conditions that were consistent with anticipated effects underlying the controls designed into these tests. In some conditions, particular melodies were especially difficult to identify – in one case after achieving a 100% correct score the subject volunteered that she was able to identify one of the melodies correctly only by elimination, being capable of recognizing all the others on that list. More significantly, strong differences in performance among the three pitch offsets (keys) appeared early in the testing for at least five conditions, consistent with the qualitative changes in allocation of harmonics across processor analysis channels that can result from even small transpositions of certain notes.

These pilot study results demonstrated the utility of controls for gross frequency range (octave), relatively small melody transpositions (musical keys), and stimulus spectral structure. One possible response to the need for more difficult tests for subject ME-16 might be to use melodies selected from much larger sets. Another option is presentation of melodies combined with directionally-distinct noise.

[Appendix A. to this report includes specifications for master lists of familiar English and German melodies and a single list of 12 familiar Polish melodies, and for other files involved in the administration of melody tests and the archiving and interpretation of their results.]

V. References

Dorman, M., Basham, K., McCandless, G., and Dove, H. (1991) “Speech understanding and music appreciation with the Ineraid cochlear implant.” *Hearing J.* **44**:32-37.

Fearn, R.A. (2001) “Music and pitch perception of cochlear implant recipients.” Ph.D. Thesis, University of New South Wales.

Gfeller, K.E. and Lansing, C. (1991) “Melodic, rhythmic, and timbral perception of adult cochlear implant users.” *J. Speech Hear. Res.* **34**:916-920.

Gfeller, K., Woodworth, G., Witt, S., Robin, D.A., and Knutson, J.F. (1997) “Perception of rhythmic and sequential pitch patterns by normally hearing adults and adult cochlear implant users. *Ear and Hear.* **18**: 252-260.

Gfeller, K., Turner, C., Woodworth, G., Mehr, M. Fearn, R., Witt, S., and Stordahl, J. (2002) “Recognition of familiar melodies by adult cochlear implant recipients and normal hearing adults.” *Cochl. Impl. Internat.* **3**:29-53.

Gfeller, K., Christ, A., Knutson, J., Witt, S., and Mehr, M. (2003) “The effects of familiarity and complexity on appraisal of complex songs by cochlear implant recipients and normal hearing adults.” *J. Mus. Therap.*, ***40** :78-112.*

Handel, S., and Erickson, M. L. (2004) “Sound source identification: the possible role of timbre transformations.” *Mus. Percep.* **21***: 587-610.*

Kong, Y-Y, Cruz, R., Jones, J.A., and Zeng, F-G. (2004) “Music perception with temporal cues in acoustic and electric hearing.” *Ear and Hear.* **25**:173-185.

Lawson, D.T. (1980) “Interval-based representations of complex tones.” *Am. J. Phys.* **48**: 615-619.

Lawson, D.T., Zerbi, M., and Wilson, B.S. (1993) “Representation of complex tones by sound processors for implanted auditory prostheses.” Speech Processors for Auditory Prostheses, Fourth Quarterly Progress Report, NIH Project N01-DC-2-2401.

Lawson, D.T., Wilson, B.S., and Zerbi, M. (1994) “Further studies of complex tone perception by implant patients.” Speech Processors for Auditory Prosthesis, Eighth Quarterly Progress Report, NIH Project N01-DC-2-2401.

Lawson, D.T. (2000) “MusiCI: a musical tone synthesizer for cochlear implant users.” Speech Processors for Auditory Prostheses, Eighth Quarterly Progress Report, NIH Project N01-DC-8-2105.

Moore, B.C. J. (2003) “Coding of sounds in the auditory system and its relevance to signal processing and coding in cochlear implants.” *Otol. and Neurotol.*, **24**:243-254.

Schatzer, R., Zerbi, M., Sun, X., Cox, J.H., Wolford, R.D., Lawson, D.T., and Wilson, B.S. (2003) “Recent enhancements of the speech laboratory system.” Speech Processors for Auditory Prostheses, Fifth Quarterly Progress Report, NIH Project N01-DC-2-1002.

VI. Plans for the next quarter

Among the activities planned for the next quarter are:

- A visit by Dr. Artur Lorens, International Center of Hearing and Speech, Poland, October 18-20.
- Presentation by Wilson on "Update on EAS studies at the Research Triangle Institute" to the Hearing Preservation Workshop III, Dallas, TX, October 15-17.
- Wilson to chair session on Neural Enhancement at the Hearing Preservation Workshop III, Dallas, TX, October 15-16.
- A visit by consultant Mariangeli Zerbi to collaborate on implementing the Pulsar interface, November 12-13.
- Presentation by Wilson on "Auditory prosthesis as a paradigm for successful neural interfaces" to the Neural Interfaces Workshop, National Institutes of Health, Bethesda, MD, November 15-17.
- A visit by Nucleus percutaneous subject NP-6, November 15-16.
- A visit by Nucleus percutaneous subject NP-8, November 22-23.
- A visit by Nucleus percutaneous subject NP-7, November 29 – December 3.
- A visit by Nucleus percutaneous subject NP-9, December 6-10.

VII. Acknowledgments

We thank volunteer research subjects NP-7 and NP-9 for their participation in studies during this quarter.

Appendix 1: Summary of reporting activity for this quarter

Publications

1. Dorman MF, Wilson BS: The design and function of cochlear implants. Am Scientist 92: 436-445, 2004.

Presentations

1. Skarzynski H, Wilson BS, Lorens A, Piotrowska A: Electroacoustic stimulation in patients with partial deafness. XXXI Congress of the European Society for Artificial Organs, Warsaw, Poland, September 8-11, 2004

Appendix A: File specifications for melody recognition tests

Master Lists of Familiar English and German Melodies,
and a single list of 12 Familiar Polish Melodies:

[Each entry includes three lines: title or other label for recognition, unique three-character identifier for internal use, and 16 comma-separated integers defining the pitch sequence.]

English

Angels We Have Heard on High
ang
4,4,4,7,7,5,4,4,4,2,4,7,4,2,0,0
All Things Considered theme
atc
7,12,9,5,2,7,4,0,3,8,5,1,5,7,8,8
Blue Bells of Scotland
bel
7,12,12,11,9,7,7,9,12,4,4,5,2,0,0,0
Westminster Chimes (Big Ben)
ben
9,5,7,0,0,7,9,5,9,5,7,0,0,7,9,5
Oh Beautiful for Spacious Skies
bfl
5,5,2,2,5,5,0,0,2,3,5,7,9,5,5,5
There Was a Farmer Had A Dog (Bingo)
bgo
0,5,5,5,0,2,2,0,0,5,5,7,7,9,9,5
Blue Tail Fly
blu
0,5,7,5,4,2,2,10,2,0,4,7,10,9,5,5
My Bonnie Lies Over the Ocean
bon
0,9,7,5,7,5,2,2,0,0,0,0,0,0,9,7
Oh My Darling Clementine
clm
5,5,5,5,0,0,9,9,9,9,5,5,5,9,12,12
Camptown Ladies Sing this Song
cmp
5,5,2,5,7,5,2,2,2,0,0,0,2,0,0,0
My Country 'Tis of Thee
cou
1,1,3,0,1,3,5,5,6,5,3,1,3,1,0,1
Twenty Froggies Went to School
frg
0,9,9,10,9,7,7,7,0,7,7,9,7,5,5,5
God Rest Ye Merry Gentlemen
god
2,2,9,9,7,5,4,2,0,2,4,5,7,9,9,9
Morning Song (from Peer Gynt)
gyn
7,4,2,0,2,4,7,4,2,0,2,4,7,4,7,9
Happy Birthday to You
hbd
0,2,0,5,4,4,0,2,0,7,5,5,0,12,9,5
Surprise Symphony (Haydn)
hdn
5,5,7,7,12,12,9,9,10,10,7,7,4,4,0,0
There's a Hole in the Bucket
hol
7,7,9,0,0,2,5,0,2,5,0,2,5,7,9,0
Hark the Herald Angels Sing
hrk
0,5,5,4,5,9,9,7,12,12,12,10,9,7,9,9

Old Hundredth (Doxology)
hun
5,5,4,2,0,5,7,9,9,9,9,7,5,10,9,7
If You're Happy and You Know It
ifh
0,0,5,5,5,5,5,5,4,5,7,7,7,7,7,7
Jesu Joy of Man's Desiring
jes
0,2,4,7,5,5,9,7,7,12,11,12,7,4,0,2
Joyful Joyful (Ode to Joy)
joy
4,4,5,7,7,5,4,2,0,0,2,4,4,2,2,2
Little Brown Jug
jug
0,3,3,3,1,5,5,5,7,7,5,7,8,10,12,12
Jupiter (Holst "The Planets")
jup
10,5,7,8,7,5,10,5,7,0,2,3,10,5,7,8
Lightly Row
lit
7,4,4,4,5,2,2,2,0,2,4,5,7,7,7,7
Aura Lee / Love Me Tender
lov
2,3,2,3,5,0,5,5,3,2,0,2,3,3,3,3
Old MacDonald Had a Farm
mac
5,5,5,0,2,2,0,0,9,9,7,7,5,5,5,0
Mary Had a Little Lamb (London Bridge)
mar
4,2,0,2,4,4,4,4,2,2,2,2,4,7,7,7
Have You Seen the Muffin Man
muf
2,0,5,5,7,9,5,5,4,2,7,7,5,4,0,0
This Old Man
old
5,2,5,5,5,2,5,5,7,5,3,2,0,2,3,3
Over the River and Through the Woods
ovr
4,4,4,4,0,2,4,4,6,4,4,4,9,9,9,7
Peter Peter Pumpkin Eater
pet
9,5,7,5,2,5,0,5,9,5,7,5,2,5,0,5
Poor Little Buttercup
poo
0,2,5,4,2,0,0,2,5,4,2,0,5,4,5,7
Pop Goes the Weasel
pop
0,5,5,5,7,7,7,8,12,8,5,5,0,5,5,5
She'll be Coming 'Round the Mountain
sbe
3,5,8,8,8,8,5,3,0,3,8,8,8,8,8,8
Skip to My Lou
skp
5,5,1,1,5,5,8,8,3,3,0,0,3,3,6,6
Are You Sleeping? (Frere Jacques)
slp
0,2,4,0,0,2,4,0,4,5,7,7,4,5,7,7
Spartan Fight Song
spt
0,1,2,1,0,1,2,2,0,0,2,4,5,9,9,9
Sur le Pont d'Avignon
sur
5,5,5,5,7,7,7,7,9,10,12,5,4,5,7,0
I'd Like to Teach the World to Sing
tch
2,0,2,5,2,0,2,5,2,7,9,7,9,7,7,7
Man on the Flying Trapeze
tpz
0,0,5,7,9,9,9,10,2,2,7,7,7,0,4,5

Twinkle Twinkle Little Star
twk
0,0,7,7,9,9,7,7,5,5,4,4,2,2,0,0
Hail the Victors
vic
4,4,0,2,4,0,2,4,5,5,2,4,5,2,4,5
Good King Wenceslas
wen
5,5,5,7,5,5,0,0,2,0,2,4,5,5,5,5
Yankee Doodle
yan
5,5,7,9,5,9,7,0,5,5,7,9,5,5,4,4

German

Alle meine Entchen
ent
0,2,4,5,7,7,7,7,9,9,9,9,7,7,7,7
Haenschen klein
han
7,4,4,4,5,2,2,2,0,2,4,5,7,7,7,7
Es tanzt ein Bi-Ba-Butzemann
est
0,5,5,12,12,9,9,5,5,7,7,0,0,5,5,5
Hopp, hopp, hopp! Pferdchen lauf Galopp
hhh
0,0,4,4,7,7,7,7,7,5,4,2,0,0,0,0
Schlaf, Kindlein, schlaf
sch
4,4,2,2,0,0,0,0,7,7,5,5,4,4,4,4
Ein Maennlein steht im Walde
man
0,5,7,9,10,12,12,14,10,9,9,7,7,5,5,5
Traria, der Sommer der ist da
tra
5,5,9,9,7,7,7,0,2,0,2,4,5,5,5,12
Alle Voegel sind schon da
vog
0,0,0,4,7,7,12,12,9,9,12,9,7,7,7,7
ABC, die Katze lief in Schnee
abc
4,4,5,5,7,7,7,12,7,5,4,2,0,0,0,7
Laterne, Laterne
lat
5,2,2,0,5,2,2,0,0,2,2,5,5,2,2,0
Stille Nacht, heilige Nacht
stl
3,5,3,0,0,0,3,5,3,0,0,0,10,10,10,7
Summ, summ, summ
sum
7,7,5,5,4,4,4,4,2,4,5,2,0,0,0,0
Backe, backe Kuchen / Liebe, liebe Sonne
bac
3,3,5,5,3,3,0,0,3,3,5,5,3,3,0,0
Das Lied der Deutschen
deu
1,1,1,3,5,5,3,3,6,6,5,5,3,0,1,1
Meister Jakob / Frere Jacques
fre
0,2,4,0,0,2,4,0,4,5,7,7,4,5,7,7
Londons Bruecke
lon
4,2,0,2,4,4,4,4,2,2,2,2,4,7,7,7
Europaeische Hymne / Ode an die Freude
eur
4,4,5,7,7,5,4,2,0,0,2,4,4,2,2,2
O Tannenbaum
tan
0,5,5,5,5,7,7,9,9,9,9,9,7,9,10,10
Im Maerzen der Bauer
mar
0,5,5,9,7,7,10,4,4,7,5,5,0,5,5,9
Zum Geburtstag / Happy Birthday
geb
0,2,0,5,4,4,0,2,0,7,5,5,0,12,9,5
Ein Voegel wollte Hochzeit machen
ein
7,7,4,7,4,5,2,5,2,4,0,7,4,2,7,7
Wenn ich ein Voeglein war
wen
0,0,0,4,2,0,4,4,4,7,5,4,7,5,4,2

Haensel und Gretel
hug
7,7,4,5,7,7,4,0,2,2,2,4,0,0,0,0
Kling, Gloeckchen, klingelingeling
kli
3,3,3,3,0,0,1,1,3,5,3,5,3,3,3,3
Bruederchen, komm tanz mit mir
bru
0,5,5,5,4,7,0,0,0,7,7,7,5,9,0,0
Ihr Kinderlein kommet
ihr
5,5,5,2,5,5,5,2,5,3,3,0,3,2,2,2
Zu Betlehem geboren
bet
0,5,7,9,7,5,5,4,5,7,7,9,7,5,5,5
Der Kuckuck und der Esel
kue
5,2,5,2,3,2,2,2,2,0,4,0,4,2,2,2
Liebe Schwester tanz mit mir
lie
0,5,5,5,4,7,0,0,0,4,7,11,9,12,5,5
O du Froehliche
fro
3,3,5,5,3,1,0,1,3,3,5,5,3,1,0,1
Ach du lieber Augustin
aug
12,12,12,14,12,10,9,9,5,5,5,5,7,7,0,0
Hoppe, hoppe, Reiter
hhr
3,3,5,5,3,3,0,0,3,3,5,5,3,3,0,0
Maikaefer, flieg
mai
4,4,2,2,0,0,0,0,4,4,2,2,0,0,0,0
Zeigt her eure Fuesschen
zei
0,5,5,5,9,5,5,5,0,5,5,5,9,7,7,7
Kuckuck, Kuckuck
kuc
7,4,4,7,4,4,2,0,2,0,0,0,2,2,4,5
Spannenlanger Hansel
spn
0,0,0,2,4,4,4,4,2,2,2,4,0,0,0,0
Ich hatt' einen Kameraden
ich
0,0,5,5,9,9,9,9,7,7,5,5,5,5,0,0
Kommt ein Vogel geflogen
kom
2,3,5,5,2,2,2,2,2,2,0,0,0,2,3,3

Polish

Plynie Wisla, Plynie
ply
5,5,5,0,9,7,5,4,2,5,4,2,2,0,0,0
W Zlobie Lezy
zlo
0,0,5,7,9,9,7,5,7,9,10,10,9,10,12,12
Wsrod Nocnej Ciszy
wsr
5,5,7,4,5,5,0,0,9,9,10,7,9,9,9,9
Pytala Sie Pani
pyt
0,5,5,7,9,9,14,12,12,12,12,12,0,5,5,7
Przybiezeli do Betlejem
prz
1,0,1,3,5,3,5,6,8,8,10,10,8,8,8,8
Pojdzmy wszyscy do Stajenki
poj
1,1,1,0,1,1,3,3,1,1,6,6,10,10,6,6
Pasterze Mili
pas
3,3,0,8,8,8,7,5,5,3,3,3,3,3,0,8
Goralu Czy Ci Nie Zal
gor
0,5,5,5,5,7,9,2,2,2,7,7,5,4,4,4
Gdy Sliczna Panna
sli
0,0,2,4,5,5,5,5,7,10,9,7,7,7,5,5
Gdy Sie Chrystus Rodzi
chr
7,4,12,9,9,9,7,7,4,4,4,2,2,2,0,0
Dzisiaj W Betlejem
dzi
5,5,5,0,5,7,9,9,9,7,9,10,12,14,12,12
Czyja to Dziewczyna
czy
7,7,0,12,12,12,11,11,11,11,11,11,9,9,12,11

Archive file specifications

RTI Melody Test File Conventions
v.21

```
ARCHIVE FILE
file name:  XXmellog.txt
location:  c:\pats\XX\
       where XX is a two- or three-character patient ID
       and the c:\pats\XX\ is superceded by any path set as "RTIPATS" in a given PC's
       environment
format: two ASCII lines appended per test

Beg   No of Chars  Description                                         Source for
                                                               Streaming Version

01         3      patient ID (left justified)                          melparams.txt
04        10      date-time stamp for beginning of test (yymmddhhmm)   Test adm prog
14        16      processor name (left justified)                      melNNMMK0.amp
30         2      melody list number (patient specific)                melparams.txt
32         1      randomization number (list length dependent)         Test adm prog
33         1      test condition (F=freefield, D=direct, H=headphone)  Test adm prog
34         4      reference (lowest) pitch in Hz (right justified)     melparams.txt
38         1      spectral content (A=allharms, O=oddharms,            melparams.txt
                  F=fundonly,S=special [e.g. sampled instrument])
39         2      pitch offset for exemplar 1s (1=reference pitch)     melparams.txt
41         2      pitch offset for exemplar 2s                         melparams.txt
43         2      pitch offset for exemplay 3s                         melparams.txt
45         1      ear(s) (L=leftonly, R=rightonly, B=both)             Test adm prog
46         5      note duration in samples at 44.1 ks/s                melparams.txt
51         2      melodies/list (ignoring multiple offsets)            melparams.txt
53         1      presentations of each melody per test                melparams.txt
                  (including offsets, 1..3)
54         2      notes/melody                                 melNNMMK0.wav filenam (NN)
56         1      freq dependence of harmonic amplitudes (0=unknown or melparams.txt
                  uncontrolled, 1= 1/f, 2=1/ff, 3=1/fff)
57         1      noise condition (0=quiet, F=front, L=left,R=right)
58         2      SNR (pos or neg in dB, ignored if previous character is 0)
60                CR-LF
01         2(melodies)(presentations)  melody number responses
                  CR-LF

** Note that the filename of the .amp file above mirrors the name of the corresponding .wav file.
```

MELODY LIST FILES
file names: XXmelNN.txt
where NN is a serial number assigned to each subject's melody lists as they are created
location: same as XXmellog.txt, i.e. in the individual subject's subfolder, typically c:\pats\XX\
format: three ASCII lines per melody, each terminated by CR-LF

first line contains only the melody title for display to subject
second line contains only a 3-character abbreviation for labeling matrices
third line contains sequence of 16 offsets, comma-delimited, in semitones
minimum offset = 0, maximum offset = 24

RANDOMIZATION FILES
file names: randR.txt
where R is the randomization number (1..7)
location: c:\tests\
superceded by any path set as "RTITEST" in a given PC's environment
format: one ASCII line per presentation, each terminated by CR-LF

each line contains a 3-digit sequence
the first two digits identify the melody (01..20)
the third digit identifies which pitch offset (1,2,or 3) [presentation no.]

[The files are designed to accommodate up to 20 different melodies and up to 3 presentations of each per test. For tests using fewer melodies and/or presentations of each, testing software should simply ignore randomization files outside those ranges.]

NOTE WAVEFORM FILES
filenames: not1.wav .. not25.wav
noteparams.txt FILE
four ASCII lines describing the notes in the associated [same (sub)directory] set
note duration in samples
reference pitch in Hz
harmonic content: A=all[1-9], O=odd[1,3,5,7,9], F=fundamental[1 only]
freq. dep. of harmonic amplitudes [1=1/f, 2=1/ff, 3 = 1/fff]

MELODY WAVEFORM FILES
file names: melNNMMK0.wav
where NN is the number of notes/melody, MM the melody number within the list,
and K the presentation (1..3, perhaps with different pitch offsets)
format: RIFF WAVEfmt file, 44-byte header
The final zero in the file name will be changed to F, L, or R, if and when
` noise is mixed in.
melparams.txt FILE
eleven ASCII lines describing the melodies in the associated [same (sub)directory] set
the first four lines are copied from the noteparams.txt for the notes used
note duration in samples
reference pitch in Hz
harmonic content
freq. dep of harmonic amplitudes
patient ID
melody list number (patient specific)
pitch offset for first exemplars
pitch offset for second exemplars
pitch offset for third exemplars
melodies / list
presentations of each melody / test
[Note that the same folder may contain more than one set of melody .WAV files produced using the same set of notes, so long as they are described by the same melparams.txt file. (e.g. the sets may have different numbers of notes per melody, as reflected in the names of the .WAV files.)]