Melodic Contour Identification Training in Cochlear Implant Users with and without a Competing Instrument

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ABSTRACT

For cochlear implant (CI) patients, music perception can be especially difficult when multiple instruments are played. The relatively poor spectro-temporal resolution does not allow CI patients access to pitch and timbre cues that may be used to segregate and stream competing melodies and instruments. Auditory training improves CI users' melodic pitch perception. Given the more difficult and more common listening condition of multi-instrument music, it may be more beneficial to train with multiple instruments than with a single instrument. In this study, CI subjects were trained to identify melodic contours. One group ("no masker") trained while listening only to the target contours. The other group ("masker") trained while listening to target contours presented with a competing masker. Before training, baseline melodic contour identification was measured with and without a masker; the timing, pitch, and timbre of the masker was systematically varied. Subjects trained at home for a total of 10 hours during the 1-month training period. Results showed that baseline performance was poorer with the masker than without, and that performance improved with both training methods. However, the magnitude of improvement was greater for the masker group, suggesting that the more difficult training provided better outcomes.

KEYWORDS: Cochlear implant, music, training

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Learning Outcomes: As a result of this activity, the participant will be able to (1) describe the difference between multiple instrument and single instrument melodic pitch perception and (2) describe the impact of a masker on melodic pitch perception training.

Melodic pitch perception is difficult for cochlear implant (CI) patients, and is even more difficult when multiple instruments are playing.[1–3] Given the relatively poor spectro-temporal resolution provided by CIs, CI patients cannot access timing, pitch, and/or timbre cues that aid in the segregation of competing melodies and instruments. Different from normal-hearing (NH) listeners, CI listeners have difficulty accessing these cues for auditory streaming and segregation.[4,5] Musical experience can mitigate these deficits. For example, musically experienced CI users performed better on a melodic contour identification (MCI) task, whether with a single instrument[6] or with multiple instruments.[5,7] If musical experience is a factor in CI music perception, training may help improve CI users' melodic pitch perception. However, it is unclear which training approach might be most effective. Given the more difficult and more common listening condition of multi-instrument music, is it better to train with a single instrument (relatively easy) or multiple, competing instruments (relatively difficult)?

CI patients have expressed great interest in music training,[8] and music training has been shown to significantly improve CI users' melodic pitch[6,9] and timbre perception.[10] Most studies have used only single instruments (monophonic presentation) and/or simple tasks to train CI users' music perception. Training with relatively simple stimuli may allow listeners to "gain traction" on a particular task, allowing for a less stressful learning experience. Alternatively, training with more difficult stimuli/tasks may allow for better generalization and training outcomes.[11–13] However, if the task is too difficult, training may not be productive[14] and subjects may become dispirited.

In this study, CI patients were trained to identify melodic contours presented with or without a masker contour. The timing, pitch, and/or timbre of the masker was varied to be the same as or different from the target contour. One group of subjects trained using the target contours only, whereas the other group trained with the target and masker contours. Subjects were tested before and after ~10 hours of home training.

METHODS

Subjects

Ten CI users (four male, six female) participated in this study. Table 1 shows the CI subject demographics. Adaptively measured speech recognition thresholds (SRTs), defined as the signal-to-noise ratio needed to produce 50% correct words in sentences,[15] are shown for Hearing-in-noise-test (HINT)[16] sentences at the far right of Table 1. HINT SRTs were measured as part of other studies, rather than explicitly measured for this experiment. Music experience prior to implantation is also shown in Table 1. Only two out of 10 subjects received music instruction before implantation. The mean age of CI subjects was 74 years (range: 62 to 92 years). Five subjects (S1, S4, S6, S7, and S10) participated in a related previous MCI experiment.[5] Subjects were required to be adult CI users with at least 6 months of experience with their device. Recruitment was a sampling of convenience, and subjects were randomly assigned to one of two groups as they enrolled in the study: (1) no masker group and (2) masker group. The no masker group trained only with the target contours. The masker group trained with the target contours in the presence of a simultaneously presented piano masker, the most difficult condition in a related previous study.[17] Unilateral CI users were trained and tested using only their CI device; the contralateral ear was not plugged for unilateral CI users. Bilateral CI users were trained and tested using both CI devices. CI subjects who used a hearing aid (HA) in conjunction with their CI were trained and tested using only the CI; the HA was turned off but left placed in the ear, which offered at least partial occlusion. All subjects were paid for their participation and

Table 1 Subject Demographics for all Research Participants

Subject	Gender	Age at HL Onset (y)	Age at Testing (y)	CI Experience (y)	Etiology	Device/ Strategy	Training	Music Instruction before CI	HINT SRT
S1	M	40	62	L: 12	Unknown	AB HiRes 90K/F120	No masker	Yes	2.34
S2	M	65	78	L: 12	AIED	AB HiRes 90K/F120	No masker	No	6.84
S3	F	45	92	L: 5; R: 1	Unknown	L: Nuc Freedom/ACE R: Nuc 5/ACE	No masker	No	8.17
S4	F	10	62	L: 5; R: 17	Unknown	L: AB HiRes 90K/F120 R: AB Clarion/CIS	No masker	No	−0.67
S5	F	25	65	L: 5	Otosclerosis/ Ménière's disease	Nuc Freedom/ACE	No masker	No	7.00
S6	F	37	78	R: 10	Unknown	Nuc 24/ACE	Masker	No	5.67
S7	M	40	80	L: 15	Unknown	Nuc 22/SPEAK	Masker	No	7.22
S8	F	25	77	L: 21; R: 2	Otosclerosis	L: Nuc 22/SPEAK; R: Nuc 5/ACE	Masker	No	8.17
S9	F	5	73	L: 10; R: 1	Unknown	L: AB HiRes 90K/F120 R: AB HiRes 90K/F120	Masker	No	6.89
S10	M	31	73	R: 2	Unknown	Nuc Freedom/ACE	Masker	Yes	−0.84

HL, hearing loss; AIED, autoimmune inner ear disease; R, right; L, left; AB, Advanced Bionics (Sylmar, CA); F120, Fidelity 120; Nuc, Nucleus (from Cochlear Corp., Englewood, CO); ACE, Advanced Combination Encoder (from Cochlear Corp., Englewood, CO); SPEAK, Spectral peak (from Cochlear Corp., Englewood, CO); HINT SRT, Hearing-in-noise-test speech recognition threshold, defined as signal-to-noise ratio (in dB) that produces 50% correct word in sentence recognition.

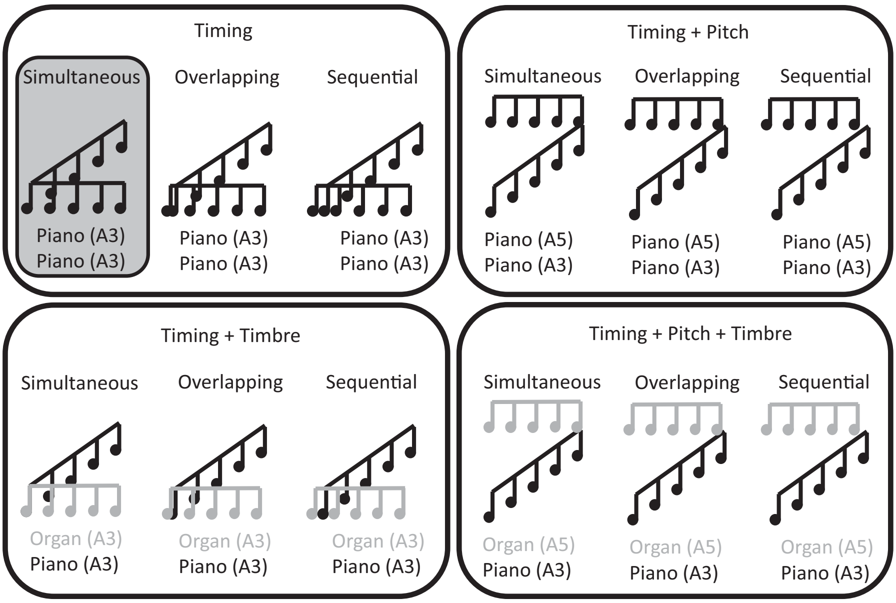

Figure 1 Illustration of the different masker cue conditions. The shaded area shows the condition used to train the masker group.

all provided informed consent before testing was begun, in accordance with the local Internal Review Board.

Stimuli

Test stimuli were similar to those used in previous MCI studies.[5–7,9,17] Target stimuli consisted of five-note melodic contours: rising, rising-flat, rising-falling, flat-rising, flat, flat-falling, falling-flat, and falling. The notes in the target contours were generated in relation to a "root note" (the lowest note in the contour) according to $f_n = 2^{n/12}\ f_{ref}$, where f_n is the frequency of the target note, n is the number of semitones relative to the root note and f_{ref} is the frequency of the root note. For all target contours, the root note was A3 (220 Hz) and the instrument was the piano. The piano was selected as the target because it was the most difficult instrument in a previous MCI study[17] and to be consistent with similar previous studies.[5,9] The note duration was 300 milliseconds and the time interval between notes was 300 milliseconds. The frequency interval between each note in the target contours was either one, two, or three semitones.

The masker conditions were created to provide different timing, pitch, and timbre cues (or combinations thereof) that could be used for contour segregation, as illustrated in Fig. 1. The masker consisted of five identical notes (i.e., a flat contour); the masker note duration was 300 milliseconds and the duration between notes was 300 milliseconds. The masker timing was either simultaneous (0 milliseconds before target), overlapping (150 milliseconds before target), or sequential (300 milliseconds before target, i.e., the masker and target were perfectly interleaved in time). The masker pitch had either the same (A3) or a higher root note (A5) as the target; note that the A5 masker pitch did not overlap with the target at all. The masker timbre was either the same as (piano) or different from (organ) the target. Note that the spectral and temporal properties are quite different between these instruments; the piano has a sharp attack, short sustain, long decay, and an irregular spectrum whereas the organ has a smooth but short attack and decay, long sustain, and a regular harmonic spectrum. In a previous study, MCI with no masker was easiest with the organ.[17] The organ was selected as the masker also to be consistent with previous studies.[5,9]

Both masker and target contours were played by sampled instruments with MIDI synthesis (Roland Sound Canvas with Microsoft Wavetable synthesis; Roland Corp., Los Angeles, CA); the piano sample was "piano 1" and the organ sample "organ 1." The long-term root-mean-square (RMS) amplitude was the same for the masker and target contours (65 dB). In total, there were 13 test conditions: MCI without a masker, MCI with a masker (three timing × two timbre × two pitch). For each condition, 54 stimuli were presented (nine contours × three semitone spacings × two repeats), and each condition was tested at least four times, or until performance asymptote was reached.

Training stimuli were similar to the test stimuli, except that novel pitch ranges were used. For the no masker training group, only the target contours were used for training. The target contour root note was any note between C3 and C6 (excluding A3), and was varied from trial to trial. For the masker training group, the target contours presented with the simultaneous piano masker were used for training (see shaded condition in Fig. 1). The target contour root note was any note between C3 and C6 (excluding A3), and was varied from trial to trial; the target and masker root note was always the same (A3), thus providing minimal cues for contour segregation and the most challenging training condition.

Testing Procedures

Testing procedures were identical to those in a previous related MCI study.[5] Baseline performance for all conditions was repeatedly tested (typically four times) over a 4-week period until achieving asymptotic performance, similar to previous training studies.[6,18,19] Before initial testing, subjects were given a quick preview of the stimuli to familiarize them with the test procedures. During the preview, the subjects clicked on one of the nine target contours shown onscreen; the associated stimulus was played back after each click. The preview period was typically less than 3 minutes. Given the number of conditions, each testing session lasted ~3 hours. Subjects were regularly given breaks (typically, every 40 minutes) to reduce fatigue during testing. Subjects were told that the masker would consist of the same note repeated five times, played by the piano or organ. During testing, a stimulus was randomly selected from the set and presented to the subject, who responded by clicking on one of nine response boxes labeled with text and picture depicting the nine target contours. Subjects were allowed to repeat the stimulus a maximum of three times. No trial-by-trial feedback was provided. Test conditions were randomized within and across subjects. Each condition was tested twice and the mean performance for each subject was calculated. All stimuli were presented at 65 decibels sound pressure level (dB SPL, A-weighted) in the sound field via a single loudspeaker located directly in front of the listener (1 m away). CI subjects were tested while using their clinical processors and settings.

Training Procedures

Training procedures were generally similar to those in a previous MCI training study.[6] However, unlike the adaptive training procedure used the previous study,[6] for each training exercise, 25 target stimuli were randomly selected from among the training target contours with one-, two- or three-semitone spacing. Thus, during a training exercise, subjects may hear any one of the nine contours with any one of the three semitone spacings. Subjects trained at home using custom software (Sound Express, developed by Qian-Jie Fu at House Research Institute) loaded onto their home computers or loaner laptops. Subjects were instructed to train for a half hour per day, 5 days per week for 1 month, for a total of 10 hours of training. Subjects were instructed how to use the software, how to adjust the volume on the computer speakers, and how to contact researchers in the event of difficulty.

For both subject groups, training was similar (except for the stimuli). During training, a stimulus was randomly selected from the stimulus set and presented to the subject, who responded by clicking on one of nine response boxes labeled with text and picture according to the nine target contours. If the subject responded correctly, visual feedback was provided and a new stimulus was presented. If the subject responded incorrectly, audio and visual feedback was presented, allowing the subject to repeatedly compare their response to the correct response, after which a new stimulus was presented. Each training exercise consisted of 25 trials, and subjects generally completed three to four exercises during each session.

Note that there was no attempt to monitor music listening experience outside of the laboratory; it is possible that such experience might influence training outcomes.

RESULTS

The training software logged the time, date, and total time spent training for each subject. All subjects completed the required 10 hours training. The mean number of training hours completed was 11.28 hours (range: 9.96 to 15.4 hours).

For each subject, mean baseline performance for each condition was calculated across the final three test sessions; group means were calculated across individual subject means. Group mean posttraining performance was calculated across individual subjects. Figure 2 shows mean performance for the no masker and masker subject groups, before and after training, as a function of cue condition. Before training, mean MCI performance for the no masker group was 58.9% correct with the target contours alone. With a competing masker, mean MCI performance (across timing conditions) dropped to 52.1%, 54.9%, 55.9%, and 54.2% correct when timing, timing + pitch, timing + timbre, and timing + pitch + timbre cues were available, respectively (see Fig. 2). After training, mean performance improved to 67.6% correct with the target contours alone. With a competing masker, mean posttraining performance (across timing conditions) improved to 56.5%, 60.3%, 61.9%, and 59.2% correct when timing, timing + pitch, timing + timbre, and timing + pitch + timbre cues were available, respectively. Note that there was great intersubject variability in terms of baseline performance and posttraining gains, as shown in Table 2. Baseline performance ranged from 12.1% correct (subject S2 when pitch and timbre cues were available, simultaneous presentation of masker and target) to 95.1% correct (subject S4 when pitch cues were available, overlapping presentation of masker and target). Posttraining gains ranged from −4.1 percentage points (subject S3 when no timbre or pitch cues were available, sequential presentation of masker and target) to 44.2 percentage points (subject S3 when no masker was presented).

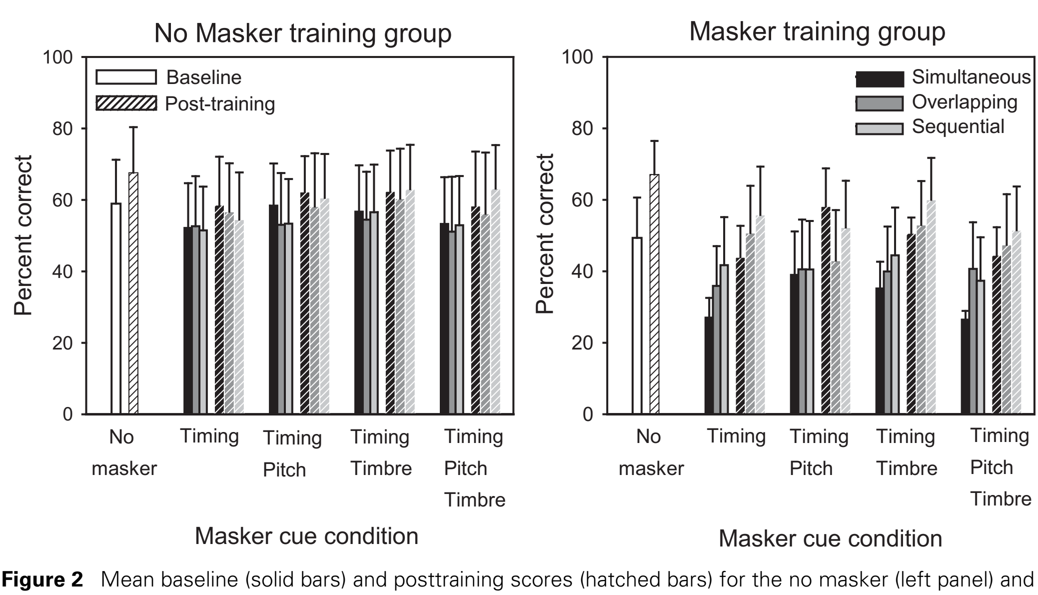

Figure 2 Mean baseline (solid bars) and posttraining scores (hatched bars) for the no masker (left panel) and masker groups (right panel), as a function of cue condition. The error bars show one standard error.

Table 2 Baseline Performance and Posttraining Gains for Individual Subjects

Masker Cue Conditions		No Masker	Timing			Timing + Pitch			Timbre + Timing			Timbre + Timing + Pitch		
Subject			Sim	Over	Seq	Sim	Over	Seq	Sim	Over	Seq	Sim	Over	Seq
S1	Base	68.6	63.0	65.8	67.3	66.7	66.1	60.2	64.8	64.2	67.6	55.0	63.0	63.0
	Post	−3.8	0.0	6.5	−0.6	5.5	6.1	8.3	5.6	2.5	8.3	−1.3	3.7	11.1
S2	Base	24.1	13.9	19.5	17.9	29.6	25.9	29.6	24.1	16.7	24.7	12.1	14.9	17.6
	Post	−3.7	−0.9	−2.8	−1.2	7.4	3.7	5.6	−1.9	13.0	6.8	−1.0	1.9	20.4
S3	Base	39.1	42.0	23.0	35.6	32.4	15.3	25.0	24.6	41.5	27.2	40.3	16.1	26.0
	Post	44.2	4.3	14.1	−4.1	8.3	1.4	4.6	8.7	2.9	8.0	4.1	−1.3	5.6
S4	Base	93.8	90.1	93.8	88.3	89.5	95.1	94.4	93.8	93.2	93.8	88.9	92.0	92.6
	Post	0.6	−3.1	0.6	0.6	−0.6	−0.7	0.0	0.6	−0.6	−1.2	5.5	2.4	1.8
S5	Base	69.2	51.6	61.1	48.2	73.8	62.7	57.4	65.0	68.1	69.5	70.0	69.8	65.3
	Post	5.8	31.7	1.8	20.4	−1.5	15.0	17.6	16.4	10.6	10.2	18.0	18.2	12.5
S6	Base	40.7	16.4	22.2	18.0	28.7	28.7	20.8	22.2	24.6	22.2	23.5	20.4	16.8
	Post	5.6	6.7	−1.8	−1.3	13.9	−6.5	−2.3	17.6	8.7	3.7	2.4	3.7	7.3
S7	Base	40.5	28.8	20.9	34.8	25.9	17.6	33.4	25.8	30.2	41.0	26.2	21.9	31.5
	Post	36.4	23.1	19.9	31.8	23.1	0.9	9.2	14.9	23.5	22.0	12.7	−4.3	11.1
S8	Base	26.2	14.8	21.5	25.0	19.9	20.6	18.7	21.5	19.2	24.9	19.8	26.9	19.5
	Post	31.3	12.0	35.7	25.9	38.4	16.4	38.7	31.3	35.8	32.6	45.1	21.3	30.6
S9	Base	46.9	30.0	36.1	37.0	33.5	42.3	36.5	42.4	40.2	38.5	28.5	44.4	35.0
	Post	8.7	16.3	0.9	8.4	8.1	−2.5	8.0	−10.9	13.5	16.1	3.0	4.6	8.5
S10	Base	92.4	45.1	78.9	93.7	86.8	93.5	93.0	87.9	61.7	95.8	34.3	89.8	84.0
	Post	6.7	26.2	19.2	5.4	12.3	3.7	5.1	12.2	−4.3	3.2	26.8	8.4	13.2

Base, baseline performance in percent correct; Post, posttraining gain in percentage points; Sim, simultaneous presentation of masker and target; Over, overlapping presentation of masker and target; Seq, sequential presentation of masker and target.

Mean baseline performance for the masker group was 49.3% correct when no masker was presented. When a masker was presented, mean baseline performance (across timing conditions) dropped to 38.9%, 40.0%, 39.9%, and 38.4% correct when timing, timing + pitch, timing + timbre, and timing + pitch + timbre cues were available, respectively. After training, mean performance improved to 67.0% correct when no masker was presented. When a masker was presented, mean posttraining performance (across timing conditions) improved to 50.1%, 51.1%, 54.5%, and 47.9% correct when timing, timing + pitch, timing + timbre, and timing + pitch + timbre cues were available, respectively. As with the no masker group, there was great intersubject variability in terms of baseline performance and posttraining gains (see Table 2). Baseline performance ranged from 14.8% correct (subject S8 when no pitch or timbre cues were available, simultaneous presentation of masker and target) to 95.8% correct (subject S10 when timbre cues were available, sequential presentation of masker and target). Posttraining gains ranged from −10.9 percentage points (subject S9 when timbre cues were available, overlapping presentation of masker and target) to 44.2 percentage points (subject S8 when pitch and timbre cues were available, simultaneous presentation of masker and target).

Because of the small number of subjects and the large intersubject variability, nonparametric tests were used for all statistical analyses. A Friedman repeated-measures analysis of variance (RM ANOVA) on ranked data (pooled across all subjects) showed no significant effect of masker timing (simultaneous, overlapping, or sequential) for any of the masker cue conditions (timing, timing + pitch, timing + timbre, and timing + pitch + timbre); $p > 0.05$ in all cases. A Friedman RM ANOVA on ranked data (pooled across subjects and masker timing conditions) also showed no significant effect for masker cue condition ($p = 0.592$).

Figure 3 shows posttraining performance as a function of baseline performance; data are shown for all subjects and all conditions. In 104 out of 130 cases, posttraining performance was better than baseline. A two-tailed binomial probability test showed a highly significant effect for training ($p < 0.0001$).

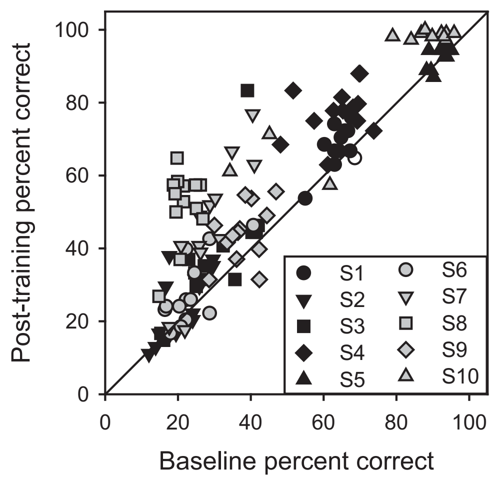

Figure 3 Posttraining performance as a function of baseline performance. Data are shown for all test conditions and all subjects. The black symbols show data for the no masker training group and the gray bars show data for the masker training group. The diagonal line represents identical baseline and post-training performance.

Figure 4 shows mean posttraining gains for the two training groups as a function masker cue condition. A Mann-Whitney rank sum test showed that the posttraining gains were larger for the masker training group than for the no masker training group ($p = 0.008$).

Several linear regressions were performed between different demographic and performance data. The results are shown in Table 3. Age at testing was significantly correlated with baseline MCI performance, and HINT SRTs were significantly correlated with baseline MCI performance. There were no other significant correlations, and there was no clear pattern of results linking device type to speech or music performance.

DISCUSSION

The present results show that both groups benefited from the music training. Although the present data are from a limited number of subjects, the results suggest that the more difficult training (with the masker) provided greater improvements in performance. Note that mean baseline performance (across all cue

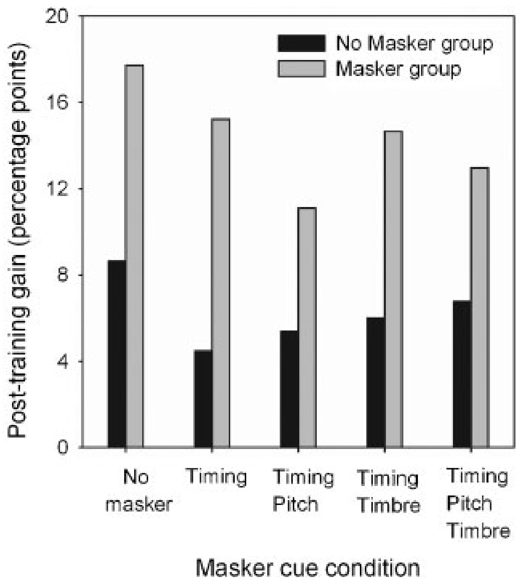

Figure 4 Mean posttraining gains for the no masker (black bars) and masker training groups (gray bars), as a function of masker cue condition (data collapsed across timing conditions).

conditions) was nearly 16 percentage points poorer for the masker group than for the no masker group, which may have allowed for greater improvement.

Although performance improved with training, there was no significant effect for the different masker cue conditions. This may reflect CI users' limited access to the timing, pitch and/or timbre cues needed to segregate the target and masker contours. Acoustic differences between masker and target may not have been preserved by CI processing. In a previous related study,[5] NH subjects were able to reliably use these cues to segregate the masker and target, whereas CI subjects were not. It is also possible that the training condition for the masker group (i.e., minimal pitch cues with no timing or timbre cues) was too difficult, and that training with the strongest possible timing, pitch, and/or timbre cues might have shown stronger improvements in some of the masker cue conditions.

Within each training group, there were both good and poor performers. Poorer performing subjects tended to improve more with training than the good performers, most likely due to ceiling performance effects. However, there was no significant correlation between mean baseline and mean posttraining gains, (see Table 3). For the six subjects who scored less than 50% correct (across all conditions), performance improved by 11.7 percentage points on average. Among these poorer performing subjects, training with the masker seemed to provide a greater improvement than when training without (14.6 versus 5.7 percentage points). For the four subjects who scored better than 50% correct (across all conditions), performance improved by only 7.6 percentage points, on average, possibly due to ceiling performance effects. Although there are

Table 3 Results of Linear Regression Analyses for Various Demographic Factors and Performance

Factor 1	Factor 2	r^2	*p* Value
Baseline MCI	HINT SRT	0.74	0.001
Posttraining gain in MCI	HINT SRT	0.20	0.134
Baseline MCI	Age at testing	0.54	0.016
Posttraining gain in MCI	Age at testing	0.06	0.510
Baseline MCI	Age at onset of profound HL	0.22	0.175
Posttraining gain in MCI	Age at onset of profound HL	0.01	0.816
Baseline MCI	CI experience	0.05	0.515
Posttraining gain in MCI	CI experience	0.12	0.334
Posttraining gain in MCI	Minutes spent training	0.31	0.119
Baseline MCI	Posttraining gain in MCI	0.12	0.319

The shaded areas indicate significant correlations. For the regressions, baseline MCI performance and posttraining gains were averaged across all conditions for each subject. MCI, melodic contour identification; HINT SRT, Hearing-in-noise-test speech recognition threshold; HL, hearing loss; CI, cochlear implant.

too few subjects to make any strong conclusions, the challenging training with the maskers seemed to provide a greater benefit for poorer performing CI patients.

The greater posttraining gains for the masker group suggest that training with more difficult stimuli or tasks may provide better training outcomes than when training with relatively simple stimuli or tasks. There are many ways to increase difficulty in a training task. Previous speech training studies have adjusted the level of difficulty by varying the number of response choices and/or acoustic contrasts among response choices, varying the signal-to-noise ratio, etc. In previous MCI training studies,[6,9] the level of difficulty was adjusted by varying the semitone spacing between successive notes in the contour. In this study, the acoustic training stimuli were varied (with or without the masker, according to subject group), and the different semitone spacing conditions were mixed within each training exercise. This was done to allow for exposure to a greater variety of training stimuli, rather than "locking in" to the most challenging semitone spacing condition. In the present study, the level of difficulty also could have been adjusted by varying the timbre of the masker contour, varying the masker contour itself, or asking listeners to identify more than one contour (or more than one instrument).

In conclusion, the results show that training can improve CI performance for relatively easy (MCI with no masker) and difficult music perception tasks (MCI with a masker). Training with the more difficult condition seemed to provide the greatest benefit. The correlation between baseline music and speech performance suggests that music training may help to improve speech performance. Music training programs for CI patients may wish to incorporate tasks with a range of difficulty to keep patients engaged and to address the many complex patterns encountered when listening to music.

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REFERENCES

1. Gfeller K, Witt S, Woodworth G, Mehr MA, Knutson J. Effects of frequency, instrumental family, and cochlear implant type on timbre recognition and appraisal. Ann Otol Rhinol Laryngol 2002; 111:349–356
2. Looi V, McDermott H, McKay C, Hickson L. Music perception of cochlear implant users compared with that of hearing aid users. Ear Hear 2008;29:421–434
3. McDermott HJ. Music perception with cochlear implants: a review. Trends Amplif 2004;8:49–82
4. Bregman AS. Auditory Scene Analysis, the Perceptual Organization of Sound. Cambridge, MA: The MIT Press; 1999:125–130
5. Zhu M, Chen B, Galvin JJ III, Fu QJ. Influence of pitch, timbre and timing cues on melodic contour identification with a competing masker (L). J Acoust Soc Am 2011;130:3562–3565
6. Galvin JJ III, Fu QJ, Nogaki G. Melodic contour identification by cochlear implant listeners. Ear Hear 2007;28:302–319
7. Galvin JJ III, Fu QJ, Oba SI. Effect of a competing instrument on melodic contour identification by cochlear implant users. J Acoust Soc Am 2009;125: EL98–EL103
8. Looi V, She J. Music perception of cochlear implant users: a questionnaire, and its implications for a music training program. Int J Audiol 2010; 49:116–128
9. Galvin JJ III, Fu QJ, Shannon RV. Melodic contour identification and music perception by cochlear implant users. Ann N Y Acad Sci 2009; 1169:518–533
10. Gfeller K, Witt S, Adamek M, et al. Effects of training on timbre recognition and appraisal by postlingually deafened cochlear implant recipients. J Am Acad Audiol 2002;13:132–145
11. Moore DR, Amitay S, Hawkey DJ. Auditory perceptual learning. Learn Mem 2003;10:83–85
12. Amitay S, Hawkey DJ, Moore DR. Auditory frequency discrimination learning is affected by stimulus variability. Percept Psychophys 2005; 67:691–698
13. Amitay S, Irwin A, Moore DR. Discrimination learning induced by training with identical stimuli. Nat Neurosci 2006;9:1446–1448
14. Moore DR, Halliday LF, Amitay S. Use of auditory learning to manage listening problems in children. Philos Trans R Soc Lond B Biol Sci 2009;364:409–420

15. Chan JC, Freed DJ, Vermiglio AJ, Soli SD. Evaluation of binaural functions in bilateral cochlear implant users. Int J Audiol 2008;47:296–310
16. Nilsson M, Soli SD, Sullivan JA. Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. J Acoust Soc Am 1994;95:1085–1099
17. Galvin JJ III, Fu QJ, Oba S. Effect of instrument timbre on melodic contour identification by cochlear implant users. J Acoust Soc Am 2008;124: EL189–EL195
18. Fu QJ, Galvin JJ III. Computer-assisted speech training for cochlear implant patients: feasibility, outcomes, and future directions. Semin Hear 2007;28:141–149
19. Fu QJ, Galvin JJ III. Maximizing cochlear implant patients' performance with advanced speech training procedures. Hear Res 2008;242:198–208