Current Biology, Vol. 14, 322–325, February 17, 2004, DOI 10.1016/j.cub.2004.02.001

Training Improves Acoustic Pattern Perception

Jessica M. Foxton,* Andrew C.B. Brown, Simon Chambers, and Timothy D. Griffiths
Auditory Group
School of Neurology, Neurobiology & Psychiatry
University of Newcastle upon Tyne Medical School
Framlington Place
Newcastle upon Tyne NE2 4HH
United Kingdom

Summary

Pitch changes that occur in speech and melodies can be described in terms of contour patterns of rises and falls in pitch and the actual pitches at each point in time. This study investigates whether training can improve the perception of these different features. One group of ten adults trained on a pitch-contour discrimination task, a second group trained on an actual-pitch discrimination task, and a third group trained on a contour comparison task between pitch sequences and their visual analogs. A fourth group did not undergo training. It was found that training on pitch sequence comparison tasks gave rise to improvements in pitch-contour perception. This occurred irrespective of whether the training task required the discrimination of contour patterns or the actual pitch details. In contrast, none of the training tasks were found to improve the perception of the actual pitches in a sequence. The results support psychological models of pitch processing where contour processing is an initial step before actual pitch details are analyzed [1, 2]. Further studies are required to determine whether pitch-contour training is effective in improving speech and melody perception.

Results and Discussion

Forty university undergraduates, aged 18–24, participated in this study. All had normal hearing and none had achieved higher than grade 2 on a musical instrument, which is the standard normally achieved after around 3 years of music lessons. The participants were assessed on a series of sequence tasks (see Figure 1), and they were then randomly allocated to one of four groups. One group trained on a pitch contour discrimination task, a second group trained on an actual-pitch discrimination task, and a third group trained on a visual-auditory contour comparison task. The fourth group did not undergo any training. All groups were then again assessed on the series of sequence tasks, which was after an average period of 11 days for all groups. There were no significant group differences for any of the sequence tests prior to training (one-way ANOVA for each sequence test: $F[3,39] = 1.33$, $p = 0.28$ for the pitch contour task; $F[3,39] = 0.78$, $p = 0.54$ for the actual pitch task; and $F[3,39] = 2.53$, $p = 0.07$ for the visual-auditory contour task).

The series of sequence tasks included a pitch-contour discrimination task. This test assessed the perception of patterns of rises and falls in pitch by requiring participants to compare transposed atonal sequence pairs. It has previously been shown that these comparisons depend upon the contour pattern of rises and falls in pitch independently of the pitch interval sizes from note to note [3]. A repeated measures analysis of variance (ANOVA) was run with the subject group as the between-subjects variable and the test session (pre- or posttraining) as the within-subjects variable. This revealed a main effect of test session ($F[1,36] = 15.2$, $p < 0.01$) and a significant interaction between test session and training group ($F[3,36] = 5.65$, $p < 0.01$) but no main effect of training group ($F[3,36] = 1.36$, $p > 0.05$). Post-hoc Bonferroni-corrected t tests revealed that there were significant differences between pre- and posttraining scores for the pitch-contour training group and the actual-pitch training group, but not for the control group or the visual-auditory contour training group ($p > 0.05$). This demonstrates that the training tasks requiring pitch contour or actual pitch comparisons are effective in improving pitch contour perception but that the visual-auditory comparison task is not. These results are shown in Figure 2. Effect sizes were calculated as the ratio of the difference between the training and control groups and the standard deviation of the two groups [4]. These revealed a strong effect for the pitch-contour training (0.94) but only a mild effect for the actual-pitch training (0.28). This suggests that pitch-contour training might be more effective in giving rise to pitch-contour perceptual improvements.

The series of sequence tasks also included a visual-auditory contour comparison task and an actual-pitch comparison task. For both of these tests, repeated measures ANOVAs were run, with the subject group as the between-subjects variable and the test session (pre- or posttraining) as the within-subjects variable. These analyses did not reveal main effects of test session or group, and the interaction terms were not significant. These results demonstrate that the training tasks were not effective in improving the perception of the actual pitches present in a sequence, nor were they able to improve the ability to match between visual and auditory contour patterns.

Performance on the training tasks is shown in Figure 3. Separate repeated measures ANOVAs were conducted for each training group, with the training day as the independent variable. These analyses revealed a main effect of training day for pitch-contour training ($F[6,54] = 5.22$, $p < 0.01$) and for actual-pitch training ($F[6,54] = 5.55$, $p < 0.01$), but not for visual-auditory training ($F[6,54] = 1.24$, $p > 0.05$). The main effect of training day for the actual-pitch task training is not in line with the pre- and posttraining scores on this measure, where no significant differences were found. We hypothesize that the main effect of training day for this group

*Correspondence: j.m.foxton@ncl.ac.uk

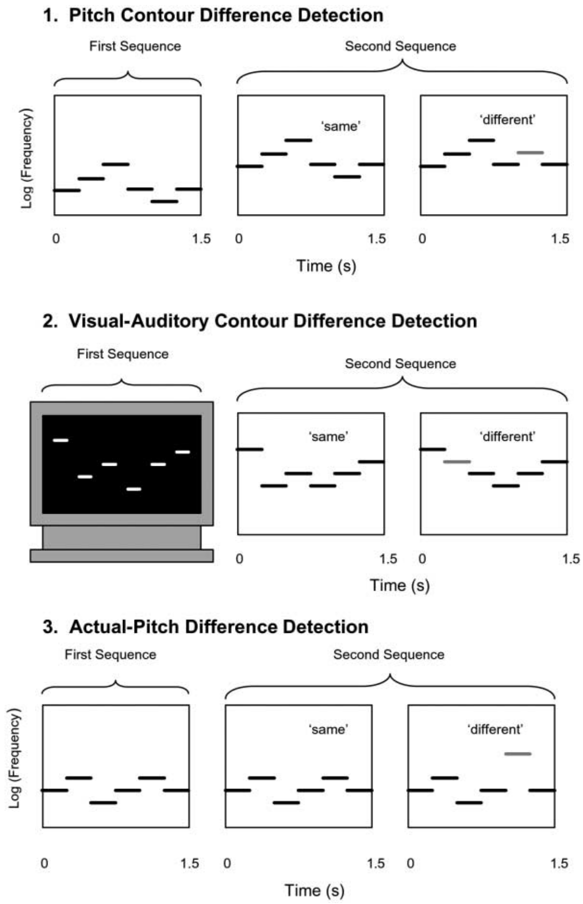

Figure 1. Sequence Discrimination Tasks

Examples are shown of items from each sequence task. Black horizontal bars represent the notes in the auditory sequences; the gray bars represent the "different" notes. For the pitch-contour difference detection task, the second sequence had a start frequency half an octave above or below that of the first sequence. Subjects were asked to ignore the overall shift in pitch level and to decide whether the sequence patterns were the same or not. For the visual-auditory contour difference detection task, subjects were first presented with a series of white bars on the computer screen (4° visual angle in length and 0.2° in height), which were presented one after the other every 250 ms (each 1.1° further to the right and 1.1° higher or lower). These remained on the screen until the between-sequence gap, after which participants heard a pitch sequence. Subjects were asked to decide whether the patterns of rises and falls were the same or different. For the actual-pitch difference detection task, participants were asked to decide whether the comparison sequences were exactly the same or not. In this test, the differences maintained the pitch-contour pattern.

might reflect the task set-up. Specifically, the training runs had interleaved sequence pairs of four, five, and six notes, and some participants reported that they initially found this confusing. As this initial confusion might be expected to subside during the first training session, these data were excluded from further repeated measures ANOVAs. These analyses revealed a main effect of training day for the contour training task only ($F[5,45] = 3.65$, $p < 0.01$), thus in line with the pre- and posttraining scores.

Improvements in pitch contour perception are of much potential practical importance, as pitch contour patterns convey important information in everyday listening situations. For instance in speech, pitch contour can convey stress patterns and also indicate whether an utterance is a statement or a question [5]. In addition, pitch contour is critical for the normal perception of music, where it is thought to form a "framework" for melody perception [1, 2]. Recently it has been shown that pitch contour perception relates to reading skills [6]. This suggests that pitch-contour training might be usefully incorporated into formal auditory training programs that are designed to ameliorate reading disorders. Effective intervention might also be provided by music lessons, which could potentially improve pitch-contour perception and literacy skills [7].

It is worth speculating upon the cause of the pitch contour perceptual improvements. It is clearly not necessary for attentional focus to be directed toward the pitch contour per se, as the actual pitch-training task also gave rise to pitch-contour improvements. However, previous studies have demonstrated that the ability to detect actual pitch differences between sequences strongly depends upon the contour pattern. Specifically, it has been found that it is easier to detect pitch differences when these occur at points of pitch-direction changes, as opposed to points where the pitch direction is maintained [8]. This implies that the actual pitches of a sequence are perceived within a contour framework, and that contour perception is therefore necessary for successful performance on the actual pitch task. This explanation could account for the pitch-contour improvements that result from training on the actual pitch task.

The present study has not demonstrated improvements in actual-pitch perception in sound sequences. This result contrasts with previous studies that demonstrated improvements in simple frequency discrimination as a result of training [9, 10]. However, previous work has shown that the ability to detect actual pitch differences between sequences is greatly limited by the presence of the surrounding pitches. This has been attributed to "informational masking," where the surrounding pitches mask the perception of the target pitch [11]. This masking is greatly reduced when the sequences are familiar. The items employed in the present study were pseudorandomly generated from trial to trial and, so, were not familiar to listeners. Therefore, the failure to demonstrate actual pitch perceptual improvements can be attributed to the presence of informational masking, which would not diminish as a result of training.

Recent studies have demonstrated that perceptual training can lead to changes in the cortical representations of sensory stimuli [12, 13]. The present study did not assess neural activity related to pitch sequence processing over the course of training, but it is reasonable to assume that changes would occur. It has been shown that pitch patterns are represented in cortical areas beyond the primary auditory cortices including the posterior superior temporal gyrus and planum polare [14]. Therefore, the perceptual improvements in the present study are likely to relate to neural changes in these structures.

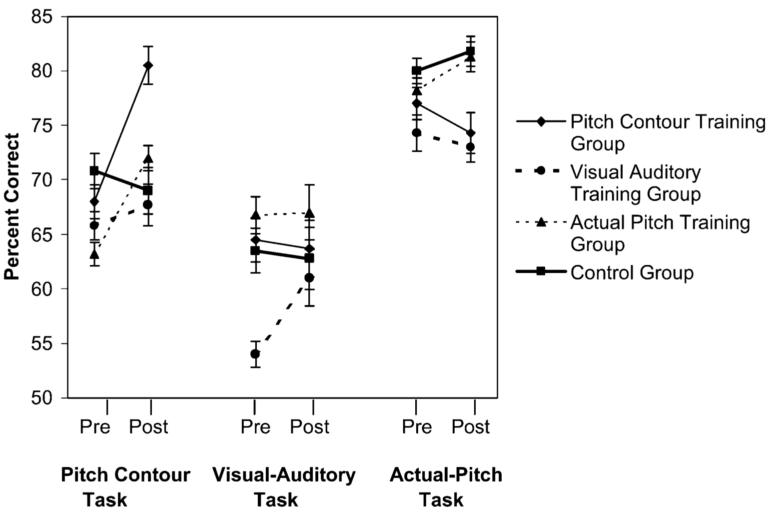

Figure 2. Pre- and Posttraining Scores on the Sequence Tests

Mean percent correct and standard errors on the pre- and posttraining tasks.

To conclude, the study demonstrates that it is possible to improve the perception of pitch-contour patterns. These improvements occur after training on tasks that require the comparison of pitch contour patterns or the actual pitches present in a sequence. It is hypothesized that the improvements will transfer to the perception of sounds in the environment, such as speech prosody and music. It will be of considerable future interest to investigate whether similar improvements can be demonstrated in children at early stages of language development and with limited musical experience.

Experimental Procedures

Pre- and Posttraining Tests

All of the tests were conducted on a laptop computer in a quiet laboratory side room. The tests were administered in a stereotyped order for both the pre- and posttraining sessions, as shown in Figure 1. Stimuli were created digitally at 44.1 kHz sample rate and 16 bit resolution and had amplitude rise and fall times of 20 ms. Presentation was at a level of 85 dB SPL through Sennheiser HD 265 headphones (Wedemark, Germany). The first tone of each test item had a frequency randomized to one of seven values, ranging from 200–350 Hz. For the auditory sequences, the notes were 250 ms pure tones taken from an octave split into seven equally spaced logarithmic steps. The sequences constituting each pair were separated by a silent gap of 1000 ms duration.

A pitch direction determination task was administered prior to the sequence discrimination tasks. The purpose of this was to familiarize participants with the experimental set-up. Subjects were asked to decide whether two separate 25 ms pure tones rose or fell in pitch. These pitch changes were always one semitone in magnitude and were separated by a 10 ms gap. There were 20 tone pairs in total, and for each item, subjects were required to press key “u” if they thought the pitch change went up and key “d” if they thought it went down.

For the sequence-discrimination tasks, participants were presented with 60 pairs of pseud-randomly generated six-element sequences. Differences between sequences only occurred at one point, avoiding the first and last notes, and were always of two notes in magnitude. Subjects were required to make a same/different judgment, and to press key “s” for same, and key “d” for different. Prior to each task, subjects were given four practice items (two same items and two different items) and were presented with feedback on the computer screen (“correct” or “wrong”). For the test runs, this feedback was not provided.

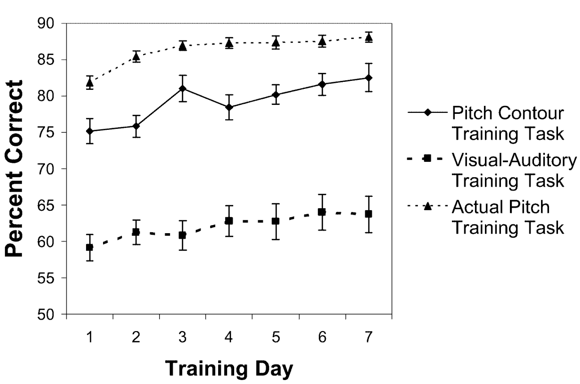

Figure 3. Performance on the Training Tasks Sessions

Mean percent correct and standard errors on the training task sessions.

Training Sessions

The training group participants completed seven training sessions, each of around 25 min duration. The sessions were completed on different days, with no gaps exceeding 3 days. For each training session, participants completed five test runs, each containing 24 sequence pairs. The stimuli were identical to those employed in the relevant pre-/posttraining task. However, the runs included sequence pairs that were four or five notes long, in addition to those with six notes (all presented in a random order). It was thought that these shorter sequences would make the tasks easier and were included to maximize the likelihood that any perceptual learning would transfer between the different sequence tasks, as transfer of learning only occurs if training items are easy enough [15]. In addition, octave splits of 5.5, 6.5, 7.5, and 8.5 were used as opposed to the octave split of 7 employed in the pre- and posttraining tests. This was to prevent participants from becoming familiar with the octave split 7 during training, which could confound the results. For all of the training tests, feedback was provided after each response (“correct” or “wrong” appeared on the computer screen).

The no-training control group participants did not complete any tasks during the training period. Rather, they only took part in the pre- and posttraining sessions, with the same time delay as the participants in the training groups.

Acknowledgments

This work was supported entirely by the Wellcome Trust.

Received: October 23, 2003
Revised: January 6, 2004
Accepted: January 6, 2004
Published: February 17, 2004

References

1. Dowling, W.J. (1978). Scale and contour; two components of a theory of memory for melodies. Psychol. Rev. *85*, 341–354.
2. Peretz, I. (1990). Processing of local and global musical information by unilateral brain-damaged patients. Brain *113*, 1185–1205.
3. Dowling, W.J., and Fujitani, D.S. (1971). Contour, interval, and pitch recognition in memory for melodies. J. Acoust. Soc. Am. *49*, 524–531.
4. Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences, Second Edition, (Hilldale, NJ: Lawrence Erlbaum Associates).
5. Lerdahl, F. (2003). The sounds of poetry viewed as music. In The Cognitive Neuroscience of Music, I. Peretz, and R. Zatorre, eds. (Oxford: Oxford University Press), pp. 413–429.
6. Foxton, J.M., Talcott, J.B., Witton, C., Brace, H., McIntyre, F., and Griffiths, T.D. (2003). Reading skills are related to global, but not local, acoustic pattern perception. Nat. Neurosci. *6*, 343–344.
7. Overy, K., Nicolson, R.I., Fawcett, A.J., and Clarke, E.F. (2003). Dyslexia and music: measuring musical timing skills. Dyslexia *9*, 18–36.
8. Dyson, M.C., and Watkins, A.J. (1984). A figural approach to the role of melodic contour in melody recognition. Percept. Psychophys. *35*, 477–488.
9. Campbell, R.A., and Small, A.M., Jr. (1963). Effect of practice and feedback on frequency discrimination. J. Acoust. Soc. Am. *35*, 1511–1514.
10. Demany, L. (1985). Perceptual-learning in frequency discrimination. J. Acoust. Soc. Am. *78*, 1118–1120.
11. Watson, C.S., Kelly, W.J., and Wroton, H.W. (1976). Factors in the discrimination of tonal patterns: II. Selective attention and learning under various levels of stimulus uncertainty. J. Acoust. Soc. Am. *60*, 1176–1186.
12. Atienza, M., Cantero, J.L., and Dominguez-Marin, E. (2002). The time course of neural changes underlying auditory perceptual learning. Learn. Mem. *9*, 138–150.
13. Jancke, L., Gaab, N., Wustenberg, T., Scheich, H., and Heinze, H.J. (2001). Short-term functional plasticity in the human auditory cortex: an fMRI study. Brain Res. Cogn. Brain Res. *12*, 479–485.
14. Patterson, R.D., Uppenkamp, S., Johnsrude, I.S., and Griffiths, T.D. (2002). The procesing of temporal pitch and melody information in auditory cortex. Neuron *36*, 767–776.
15. Ahissar, M., and Hochstein, S. (1997). Task difficulty and the specificity of perceptual learning. Nature *387*, 401–406.