Ingvalson, E.M., Leea, B., Fiebigb, P., and Wonga, P.C.M. (**2013**). "The effects of short-term computerized speech-in-noise training on postlingually deafened adult cochlear implant recipients," J. Speech Lang. Hear. Res., **56**, 81-88.
Lively, S.E., Logan, J.S., and Pisoni, D.B. (**1993**). "Training Japanese listeners to identify English /r/ and /l/. II. The role of phonetic environment and talker variability in learning new perceptual categories," J. Acoust. Soc. Am., **94**, 1242-1255.
Moore, D.R., Rosenberg, J.F., and Coleman, J.S. (**2005**). "Discrimination training of phonemic contrasts enhances phonological processing in mainstream school children," Brain Lang., **94**, 72-85.
Norris, D., McQueen, J.M., and Cutler, A. (**2003**). "Perceptual learning in speech," Cogn. Psychol., **47**, 204-238.
Oba S.I., Fu, Q.-J., and Galvin, J.J. (**2011**). "Digit training in noise can improve cochlear implant users' speech understanding in noise," Ear Hearing, **32**, 573-581.
Olson, A.D., Preminger, J.E., and Shinn, J.B. (**2013**). "The effect of LACE DVD training in new and experienced hearing aid users," J. Am. Acad. Audiol., **24**, 214-230.
Robinson, K., Gatehouse, S. and Browning, G.G. (**1996**). "Measuring patient benefit from otorhinolaryngological surgery and therapy," Ann. Otol. Rhinol. Laryngol., **105**, 415-422.
Robinson, K., and Summerfield, A.Q. (**1996**). "Adult auditory learning and training." Ear Hearing, **17**, 51S-65S.
Rosen, S., Faulkner, A., and Wilkinson, L. (**1999**). "Adaptation by normal listeners to upward spectral shifts of speech: Implications for cochlear implants," J. Acoust. Soc. Am., **106**, 3629-3636.
Shannon, R.V., Zeng, F., Kamath, V., Wygonski, J., and Ekelid, M. (**1995**). "Speech recognition with primary temporal cues," Science, **270**, 303-304.
Stacey, P.C., and Summerfield, A.Q. (**2007**). "Effectiveness of computer-based auditory training in improving the perception of noise-vocoded speech," J. Acoust. Soc. Am., **121**, 2923-2935.
Stacey, P.C., and Summerfield, A.Q. (**2008**). "Comparison of word-, sentence-, and phoneme-based training strategies in improving the perception of spectrally-distorted speech," J. Speech Lang. Hear. Res., **51**, 526-538.
Stacey, P.C., Raine, C.H, O'Donoguhe, G.M., Tapper, L., Twomey, T., and Summerfield, A.Q. (**2010**). "Effectiveness of computer-based auditory training for adult users of cochlear implants," Int. J. Audiol., **49**, 347-356.
Stecker, G.C., Bowman, G.A., Yund, E.W., Herron, T.J., Roup, C.M., and Woods D.L. (**2006**). "Perceptual training improves syllable identification in new and experienced hearing aid users," J. Rehabil. Res. Dev., **43**, 537-552.
Sweetow, R.W., and Sabes, J.H. (**2006**). "The need for and development of an adaptive Listening and Communication Enhancement (LACE) Program," J. Am. Acad. Audiol., **17**, 538-558.
Zhang, T., Dorman, M.F., Fu, Q.-J., and Spahr, A.J. (**2012**). "Auditory training in patients with unilateral cochlear implant and contralateral acoustic stimulation," Ear Hearing, **33**, e70–e79.

Perception of music and speech in adolescents with cochlear implants – A pilot study on effects of intensive musical ear training

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The purpose of this study was to examine 1) perception of music and speech of pre-lingually deaf adolescent cochlear-implant (CI) users, 2) the potential effects of an intensive musical ear training program, and 3) these adolescents' music engagement. Eleven adolescent CI users participated in a short intensive training program involving music-making activities and computer-based listening exercises. Before and after the program they completed music and speech tests. In addition, the participants filled out a questionnaire which examined music listening habits and enjoyment. A normally-hearing (NH) group provided reference data at the same points of time, but received no training. CI users significantly improved their overall music perception and discrimination of melodic contour and rhythm in particular. The NH reference group produced marginally-lower music discrimination scores at the second test. No effect of the music training was found on discrimination of emotional prosody or speech. The CI users described levels of music engagement and enjoyment that were comparable to the NH reference. The CI participants showed great commitment, but found computer-based training less relevant than music-making activities. The findings are an indication of not only the potential of training but also of the plastic potential in the young brain.

BACKGROUND

Cochlear implants (CIs) have revolutionized the lives of persons with severe or profound hearing loss (HL), but auditory processing in general and music perception in particular are hampered in CI users (Gfeller *et al*., 2005; Gfeller *et al*., 2007; Cooper *et al*., 2008; Petersen *et al*., 2012). Nevertheless, there are examples of CI-users who seem to enjoy music after repeated listening (Gfeller *et al*., 2000), and

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some studies show significantly improved music discrimination after training (Petersen *et al*., 2012). While previous studies primarily examined implant outcome in adult CI-recipients with an acquired HL, perception of music and speech in the growing population of adolescent CI users with a congenital HL has not been thoroughly investigated. Recent studies, however, indicate that to keep pace with their normal-hearing peers, supplementary measures of rehabilitation are in demand throughout adolescence. Music training may provide a strong, motivational, and beneficial method of strengthening not only music perception, but also linguistic skills, particularly the prosodic properties of speech. With this pilot study we aimed to investigate the potential impact of intensive musical training on adolescent CI-users' discrimination of music and speech and compare these measures with a normally-hearing (NH) reference. Furthermore, we aimed to examine music listening habits and music enjoyment among adolescent CI users. Finally, we intended to develop and evaluate new musical methods and materials aimed at adolescent CI users.

METHODS

Eleven adolescent CI users (six girls, five boys, M_{age} = 17.0 y, age range: 15.6-18.8 y) participated in a group-based music training program, consisting of active music making supplemented with daily computer-based listening exercises. The active training part was scheduled over six days, distributed over two weeks, adding to a total of 20 hours. The program was formed by three elements: rhythm-training, singing and ear training. The computer-based training (presented as musical quiz games) trained discrimination of melodic contour, timbre (musical instruments), and rhythm. Nine of the CI users had bilateral implants and two had unilateral implants. The mean implant experience was 9.5 years (range: 1.8-15.2 y). Ten NH peers (two girls, eight boys, M_{age} = 16.2 y, age range: 15.3-17.0 y) formed a reference group, who followed their standard school schedule and received no music training. Before and after the intervention period, both groups completed a set of tests for perception of music, speech, and emotional prosody. The participants were all recruited from Frijsenborg Efterskole in Denmark, an independent residential school, at which adolescents from the ages of 14 to 18 years can spend one or two years to finish their primary education.

Music tests

The battery of music tests used in the study was adopted from Petersen *et al*. (2012).

The musical-instrument identification test is an eight-alternative-forced-choice test which measures identification of musical timbre represented by eight musical instruments belonging to different families (brass, woodwind, string, and pitched percussion). After a brief familiarization with the instruments, the participant is required to identify the instrument playing parts of a famous Danish children's song.

Melodic-contour identification requires the participant to identify the melodic contour of a five-note sequence. The contour is either rising, falling, flat, rising-falling, or falling-rising in (i) scale steps (subtest 1) or (ii) semitones (subtest 2).

Rhythmic discrimination measures the ability to discriminate rhythmic pairs in a same/different paradigm. The rhythm patterns represented different levels of musical complexity.

Pitch ranking requires the participant to judge which of two tones played in sequence is the higher. The tones are presented in three different registers and with three different notes distances (one, three, and five semitones).

Language tests

Emotional prosody recognition tests the participant's ability to recognize three different emotions: *happy*, *sad*, and *angry*. The emotions are expressed in short everyday sentences and words like 'yes' and 'no', spoken by four different speakers (two females and two males). The test has 30 trials, ten of each emotion presented in random order.

The Danish speech material Dantale II (Wagener *et al*., 2003) measures the participant's ability to understand spoken five-word sentences in background noise. For each of the five words presented, the participant is required to select from ten alternative words or click an 'I do not know'-button. The test is organized in lists of ten sentences each. Here, the participants completed three lists, one training list and two trial lists. The test adapts to the respondents' performance by increasing or decreasing the volume of the speech. The result of the test is given as the speech reception threshold (SRT) corresponding to a level of 50% correct responses – the lower the SRT, the better the ability to hear speech in noise.

Music listening questionnaire

Prior to the intervention period, both groups completed an online questionnaire including questions concerning music listening habits and music enjoyment. Furthermore, the CI participants were required to rate the overall quality of music through the implant using five 100-point scales (0-100), each anchored with bipolar adjectives. The adjective pairs were: unpleasant-pleasant, complex-simple, fuzzy-clear, hard to follow-easy to follow, and dislike-like.

Evaluation

Shortly after the conclusion of the training program, the CI participants were asked to evaluate the music training program by filling out an online questionnaire. The questionnaire included questions about the content of the program, their perceived outcome, and use of computer applications. Scoring was done by use of five-point Likert rating scales with five as the most positive and one as the most negative.

RESULTS

Musical skills

The users in the CI group obtained higher mean test scores post-training in all five music tests compared to pre-training. The most marked progress was found in the melodic-contour identification subtest 1 ($z = -2.094$; $p = 0.036$) and in the rhythm discrimination test ($z = -2.310$; $p = 0.021$). Furthermore, the overall music progress (mean music post scores − mean music pre scores) was statistically significant ($z = -1.956$; $p = 0.050$).

Except for pitch ranking, the NH participants achieved lower mean music discrimination scores in the post-tests than in the pre-tests. Furthermore, the NH reference group obtained mean scores that were significantly higher than those of the CI participants in all music tests except the melodic-contour identification post-test (subtest 1).

Speech performance

In the emotional prosody recognition test, the CI users obtained lower mean test scores both pre- and post-training compared to the NH participants. Furthermore, the CI users showed a non-significant decline in their performance in the post-test, whereas the NH group obtained non-significantly higher mean test scores at the end of the intervention period.

In the Dantale II test, the CI users had significantly higher mean SRTs than the NH participants, which in this case indicates a poorer performance. Both groups improved their SRT values at the post-test, for the NH group with a statistical significance ($z = -2.293$; $p = 0.022$) (Fig. 1). CI performance showed a high variability with SRTs ranging from −3.9 to 10.9 dB SNR.

Music listening

The questionnaire responses showed that despite poor music-discrimination skills, the majority of the adolescent CI users enjoy listening to music and do so often (three out of 11) or every day (six out of 11). This pattern was comparable to the responses of the NH reference group. Furthermore, a majority of the CI users stated that they appreciated to listen to music (mean Likert-scale score: 3.7).

Music quality

The adolescent CI users in general gave positive ratings of the quality of music through their implant. Figure 2 shows the mean values for the five adjective pairs. The average value across the five pairs was 80.9 points.

PROJECT EVALUATION

A majority of the participants found that the content of the program was relevant. Four of the participants stated that the duration of the program was too short. The

participants in general stated that they felt their participation in the music training positively influenced their music listening outcome (mean Likert-scale score: 3.7).

On average, the participants used the computer applications for home training approximately one hour during the entire training period, which was much less than the requested 15 minutes per day. The responses concerning the potential usefulness of such applications for training of music-discrimination abilities were moderately positive. Two stated that the programs could not be useful at all.

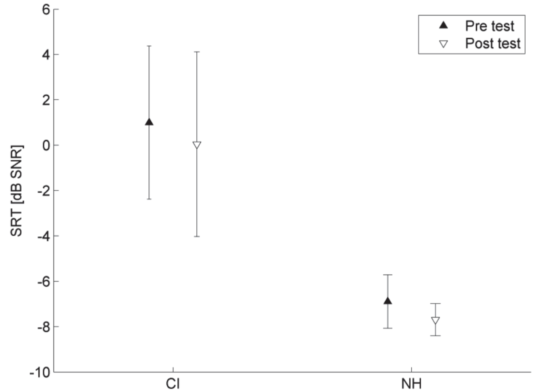

Fig. 1: Mean scores for 11 CI users and ten normal-hearing peers obtained with the Dantale II test. The error bars indicate one standard deviation.

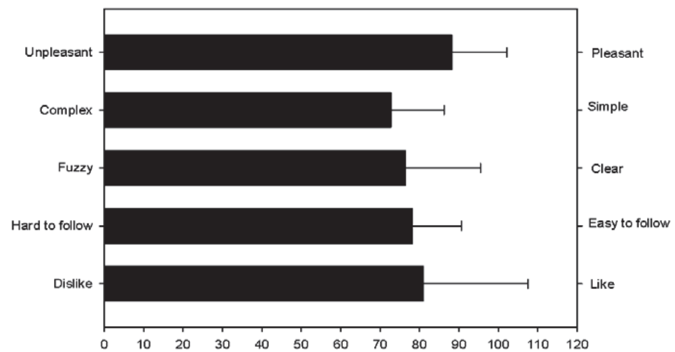

Fig. 2: Mean values for adjective pairs.

The participants agreed to a high degree that being exclusively CI users in the training group was a positive aspect. Their individual comments reflected that the feeling of having equal prerequisites for the different musical tasks was prevalent. Also, absence of embarrassment of not being able to sing in tune was regarded a positive factor.

The participants rated their general satisfaction with the program with a mean score of 86 points on a 100-point visual analog scale and their willingness to participate again with a mean score of 75 points.

DISCUSSION

On average, the adolescent CI users in this study improved their discrimination skills within all musical domains after training, which was reflected in a significant overall progress. Furthermore, they particularly improved their discrimination of rhythm and melodic contour significantly. These findings are consistent with a previous study with recently implanted adult CI users (Petersen *et al*., 2012), and suggests that changes in patterns of rhythm and in the direction of a sequence of notes are properties of music that are well preserved in the implant's sound transmission and thus most efficiently influenced by training. The NH reference group produced poorer scores at the end of the intervention period, which suggests that the CI progress is an effect of the music training and not a test learning effect. Given the brevity of the program and the duration and profound nature of these adolescents' deafness, these findings are an encouraging indication of not only the potential of training but also of the plastic potential in the young brain.

Speech perception

As expected, the NH participants all scored close to ceiling at both occasions of the emotional prosody recognition test, while the CI users produced significantly poorer results. Contrary to our hypothesis, we saw no progress in the CI users' performance, which may have several explanations. First, the progress in music discrimination was modest, which naturally lessens the chance of a transfer effect. Second, because a majority of the CI users also mastered manual and visual modes of communication, aural expressions of emotion as presented in the test may have been unfamiliar. Finally, though intensive, the training period was very short. It is possible that much more training is necessary and maybe of a more targeted nature, aiming at musical features more specifically relevant to emotional prosody.

The fact that the NH participants performed significantly better and with much less variability in the speech-in-noise test comes as no surprise. The performance gain observed in both groups, however, was unexpected and indicates an effect of learning rather than of the music training. For familiarization, all participants were given one training list in advance of the actual test at both occasions, which may have been insufficient for an optimal performance (Hernvig and Olsen, 2005; Pedersen and Juhl, 2013). However, since the test is comprehensive and loads

heavily on attention and working memory, we presumed that a total of three lists was a maximum. Although the Dantale II test is a strong tool for evaluating perception of speech in challenging conditions, we speculate that supplementary measurements of speech perception with more direct phonological focus might provide further documentation of the ability to detect aspects of music in speech and the possible benefit from music training.

Music listening and quality

The CI users performed significantly poorer than their normally-hearing peers in all music tests except the melodic-contour identification subtest 1 post-test. This confirms that perception of music through a cochlear implant is very far from the normal-hearing experience. Nevertheless, we saw no difference between the music listening habits of the CI users and their NH peers. This is in line with Gfeller *et al.* (2012), who in a survey including 31 adolescent CI users, found that a large majority of the respondents engaged in music listening and rated music as an important or very important factor in their life. Since perception of pitch, timbre, and harmony is poor with a CI, we speculate that musical features linked to timing, such as pulse, meter, form, and groove, maybe in combination with lyrics, are the main sources to these adolescents' music enjoyment and engagement. Moreover, streamed music videos on the Internet, accompanied by strong visual elements, may provide an extra dimension to the music experience, thus adding further to their musical interest.

The adolescent CI users rated the quality of music through the implant quite positively and on average significantly higher than the average rating reported in a recent survey among 163 adult CI users (Petersen *et al*., 2013). There may be manifold causes to this difference, one of them being the point of perspective. The post-lingually deaf adult CI users may tend to compare the quality of musical sounds with their recollection of what it used to sound like, while the young pre-lingually deaf CI users have no reference and therefore are less restricted in their judgment.

Evaluation

For most of the young CI users, this project was their first experience with structured and targeted music making and indeed challenging. Nevertheless, they generally responded with great enthusiasm and engagement to the different exercises and tasks. This positive attitude was further documented in the written feedback, expressed in their ratings of the program's relevance and their general satisfaction. Many of the participants even stated that the training had positively affected their perception of music and speech. Though such positive feedback may have causes of a more psychological nature and should be interpreted with caution, we conclude that active music making involving singing, rhythm and ear training is an absolutely relevant and instructive activity for adolescents with CIs.

According to our feedback, the CI participants only used the computer applications sparsely and less than requested. Obviously, being part of a community such as a boarding school, offering a variety of social activities, may leave little time for homework. The lack of commitment to this part of the program might also be due to fatigue after long and, especially for CI users, tiring school days. However, the most plausible explanation is probably that the applications provided too little excitement. Despite instant feedback and progressive design, the quizzes offered nothing with regard to animation, graphics, and competition in comparison with current computer games. We firmly believe in the potential in digital learning, also in the domain of expanding hearing capabilities, but acknowledge that to succeed in the new digital generation such applications must be fast, adaptive, competitive, offer a social dimension, and preferably be instantly accessible on a smartphone or a tablet computer.

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REFERENCES

Cooper, W.B., Tobey, E., and Loizou, P.C. (**2008**). "Music perception by cochlear implant and normal hearing listeners as measured by the Montreal Battery for Evaluation of Amusia," Ear. Hearing, **29**, 618-626.

Gfeller, K, Christ, A., Knutson, J.F., Witt, S., Murray, K.T., and Tyler, R.S. (**2000**). "Musical backgrounds, listening habits, and aesthetic enjoyment of adult cochlear implant recipients," J. Am. Acad. Audiol., **11**, 390-406.

Gfeller, K., Olszewski, C., Rychener, M., Sena, K., Knutson, J.F., Witt, S., and Macpherson, B. (**2005**). "Recognition of 'real-world' musical excerpts by cochlear implant recipients and normal-hearing adults," Ear. Hearing, **26**, 237-250.

Gfeller, K., Turner, C., Oleson, J., Zhang, X., Gantz, B., Froman, R., and Olszewski, C. (**2007**). "Accuracy of cochlear implant recipients on pitch perception, melody recognition, and speech reception in noise," Ear. Hearing, **28**, 412-423.

Gfeller, K., Driscoll, V., Smith, R.S., and Scheperle, C. (**2012**). "The music experiences and attitudes of a first cohort of prelingually-deaf adolescents and young adults CI recipients," Semin. Hear., **33**, 346-360.

Hernvig, L.H., and Olsen, S.O. (**2005**). "Learning effect when using the Danish Hagerman sentences (Dantale II) to determine speech reception threshold," Int. J. Audiol., **44**, 509-512.

Pedersen, E.R., and Juhl, P.M. (**2013**). "Examination of the learning effect with the Dantale II Speech Material," Poster presented at ISAAR 2013.

Petersen, B., Mortensen, M.V., Hansen, M., and Vuust, P. (**2012**). "Singing in the key of life: A study on effects of musical ear training after cochlear implantation," Psychomusicology, **22**, 134-151.

Petersen, B., Hansen, M., Sørensen, S.D., Ovesen, T., and Vuust, P. (**2013**). "Aspects of music with cochlear implants – Music listening habits and appreciation in Danish cochlear implant users," Poster presented at ISAAR 2013.

Wagener, K., Josvassen, J.L., and Ardenkjaer, R. (**2003**). "Design, optimization and evaluation of a Danish sentence test in noise," Int. J. Audiol., **42**, 10-17.

Auditory training

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The mapping of a sound pattern to a linguistic context is the base of acoustical communication. This process is taking place whenever language skills are acquired. However, sound cues might be changed or lost in amplification, thereby changing the sound pattern. Adaptation is required to reconnect sound with context. Focused training on this connection will speed up and improve the process. The necessity of this training is evident where hearing is restored from deafness, but a training effect is also expected in rehabilitation of gradually emerging hearing loss. Programs training speech recognition and cognitive skills exist for English speakers. They are used with some success, however the criteria for who will benefit from training are unclear. From sensory perception evaluation, training the attention to sound details and developing a language about sound attributes is well known, but the use of non-speech stimuli in auditory training has not yet been given much attention. Looking at the hearing-aid fitting process, an improved fitting could be expected if sound description ability is improved within the framework of specialized training. Music as a part of an auditory training program may increase sound property awareness to the benefit of cognitive skills also related to speech perception. Adding music improves the fun and thus the motivation of the training sessions.

BACKGROUND

Auditory training links naturally to hearing rehabilitation. The attention to the field grew in the USA around World War II, where better diagnostic capabilities and means of rehabilitation of hearing casualties from military service were severely needed. Skills such as lip-reading and 'listening practice' would accompany the prescription of hearing aids to minimize the perceived handicap of the hearing loss. As hearing aids were improved during the eighties, the auditory training as a unique part of the rehabilitation disappeared. In the late nineties, however, auditory training in the USA had a revival based on computer-controlled learning programs and new scientific results.

Auditory training has traditionally been focusing on enhancing speech understanding. However, with the complexity of modern hearing aids another training opportunity is the vocabulary of words describing sound. The link between the impression of sound and a word expressing it could be important in the process

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