Computer-Based Music Training with Hearing Impairments: Lessons From an Experiment

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ABSTRACT

From experience of teaching students with deafness or hearing impairments, we know that they both like music-related activities and want to listen to music by themselves. The individual preferences for listening among our students are however not directly related to their hearing acuity as measured by audiograms, nor can their enthusiasm for music-related activities be explained from hearing acuity alone. In order to support listening, to help improving hearing abilities, and to better their understanding and enjoyment of music, we have tested a previously developed music game for a set time period of four weeks as a training facility. To evaluate the training, a hearing capability assessment test was employed. In this paper, we describe our preliminary training trial and the current problems of music training for deaf and hard of hearing people.

1. INTRODUCTION

Contrary to some common depictions and myths about persons with deafness or hearing impairments, there are many individuals who enjoy music listening and activities [1]. We have for decades been teaching deaf and hard of hearing (DHH) engineering students at a university whose mission is through education, research, and social contribution

> *to work for the realization of a society in which people with disabilities can overcome their disabilities and become active participants in it.* [1]

From observations, we confirm that the students are engaged with and are participating in music-related activities – dancing, karaoke, and music-based computer and arcade games are among their favorites. Some of the students report that they appreciate music multimodally from vibration and sounds, while others express wishes for better music experiences entirely through listening. In order for our students to enjoy activities that involve music listening, it is necessary to either improve *hearing acuity* (measured by audiogram), or to improve the *hearing abilities* that facilitate music understanding and appreciation.

[1] https://www.tsukuba-tech.ac.jp/english/

All the undergraduate students at the department of industrial technology of Tsukuba University of Technology have hearing impairments. They are diagnosed to have at least a hearing loss over 60 decibels, at which level it is difficult to maintain a normal conversation. Even losses greater than 100 decibels are common, which corresponds to the noise level of riding a motorcycle. Hearing impairments, especially sensorineural hearing loss, involve not only deteriorated hearing thresholds but also sound distortions. Many of the students put on and use either hearing aids or cochlear implants (CI).

The performances of hearing aids have mainly been improved in terms of speech recognition – for instance, canceling noise in order to clarify speech – while non-speech sounds (music and environmental sounds) are still not examined thoroughly. Interdisciplinary research from medical doctors, speech-language-hearing therapists, audiologists, and the sound and music computing community argue for the importance of music listening for the increasing population of CI users, not least based on solid evidence for the effect with regards to brain plasticity [2]. With our observation of DHH students and from our past research on their music understanding (e.g., [3, 4]), we support this advocated focus on music listening.

Although *hearing acuity* for some can be improved by cochlear implants (CI), the subjective apprehension in music listening by CI users is still debated [5]. Also, while hearing aids can amplify and filter sounds to accommodate hearing loss, it is well known that the hearing will not necessarily be justly restored. Instead of approaching hearing acuity, we aim to study *hearing abilities* and music appreciation. Besides our experiences of DHH students who like dancing or going to karaoke, we found that *active listening* to music as a training facility can possibly improve their hearing abilities: a student who is profoundly deaf but listens to music frequently could perform our original music game the "Music Puzzle" (*MP*) [6] similarly well as students with much musical experience [7]. Thus, we have continued to evaluate *MP* as a training facility for hearing ability and can present new findings.

1.1 Auditory Training

Speech therapists and music therapists are specialists in terms of increasing quality of life for those who are having difficulties in language understanding or daily life. Speech therapists help persons with a diagnosed hearing impairment, including intervention to support language acquisition. Music therapists employ methods involving music, and typically the clients have no hearing impairment. However, there are cases where music therapy have been conducted with DHH persons, for instance with person-to-person activities [8–10], or in school settings [11, 12].

1.2 Computer-Based Auditory Training

Although auditory training with professionals have its own benefit of interactivity and easiness of adaptive training, it requires human resources; besides, the time as well as the place of therapy have restrictions. Thus, computer-based auditory training (CBAT) is emerging with the expectation of lower cost and more convenience. CBAT programs are also developed for DHH persons: Henshaw and Ferguson reviewed sixteen training programs from thirteen articles [13], and found that although CBAT can be both easily accessible and cost-efficient, the result in terms of efficacy reported from the interventions was neither consistent nor robust. This was also found for intervention with children in a review of five systems; one training system described in a research paper and four systems provided by manufacturers of hearing aids [14]. The number of systems is low because most of the proposed CBAT do not meet the criteria for review. Not surprisingly, the purpose of all the CBAT above is to improve recognition of verbal information, such as listening and communication enhancement.

1.3 Computer-Based Music Training

Music training can be analytic or synthetic. Analytic training (bottom-up training) focuses on a single music element such as melody contour. In synthetic training (top-down training), music is presented as is. Most of the computer-based music training (CBMT) designs are analytic – for instance, to listen to short melodies and being queried whether they were the same or not. By listening repeatedly to the same melodies, DHH may eventually be able to discriminate between melody contours. In contrast, music training with human intervention, like music therapy, gives synthetic training. Fuller et al. [15] compared two types of music training approaches; one CBMT with analytic training for music contour and instrument identification, and the other synthetic training derived from music therapy. The results showed that the CBMT (analytic training) improved music contour discrimination, and also a small improvement in vocal emotion identification from music therapy (synthetic training).

Although not intended for DHH persons, Bégel et al. [16] proposed the *Rhythm Workers*, a fun game for re-training rhythmic skills. The target users are persons with neurological or neurodevelopmental disorders such as Parkinson's disease or dyslexia.

Besides the cost efficiency and convenience, another advantage of CBMT is to keep users' incentives and motivation – just like the music games that DHH persons are willing to play regardless of any disability. In spite of all this, and as far as we can judge from published material, there have been no CBMT for DHH that are designed to be fun to use. Is a strong mind required to bear going through monotonous training in order to improve music appreciation? There is a shortage of such music games that can be used for training and improving hearing abilities with the goal to increase enjoyment of non-speech sounds (music and environmental sounds). Thus, we present an attempt at providing DHH persons with an enjoyable CBMT for acquiring music and environmental sounds through active listening.

2. EXPERIMENT

2.1 The Music Puzzle (*MP*)

We have conducted preliminary experiments of computer-based music training in which we used our original music game named "Music Puzzle" (*MP*) [6]. In our past study to investigate how DHH persons play *MP*, we prepared sets that included three types of sound data: speech, non-vocal music, and the mix of those two. The sound data are audio recordings typically a few seconds long.

In the gameplay, the sound is broken into a number of fragments, or "sound objects", of equal duration so that each sound object contains one part of the original sound data. There is no consistency check for the cuts, but initial or trailing spikes are removed. In the fragmentation process, each sound object can be randomly modified in pitch using a time-preserving transposition, and in timbre using either a low-pass or a high-pass filter. The modifications follow predetermined steps (explained below).

The graphically represented sound objects are placed randomly around in the display, and without having distinguishing visual features that allow recognition from appearance. Also, the objects' horizontal and vertical placement have no relation to the sound; the use of vertical placement was added to avoid a monotonous appearance and to allow the user to organize the objects during the gameplay.

Figures 1 (a) and (c) show the *MP* interface, and in (b) and (d) waveform and spectrogram representations of the sound objects. The player listens to the original recording, breaks it into sound objects (determined by a shaking gesture which use the tablet's inertia sensor data, then proceeds to listen to the sounds and adjust the manipulated pitches and timbres using a drop-down menu with randomly listed options. By clicking the "Play solution" button shown in Fig. 1c), the player can listen to the original sound. The goal of a game is to place the sound objects in correct order, and, in harder game modes, to adjust pitch and timbre to further recreate a sound recording. Thus, players must memorize the original recording, listen attentively, and continuously compare with individual and connected sounds. The game is challenging even for players without hearing impairments.

2.2 Music Training with *MP*

2.2.1 *Purpose*

Our purpose of this experiment is to investigate whether active listening required for playing the game (*MP*) improves the hearing ability of DHH.

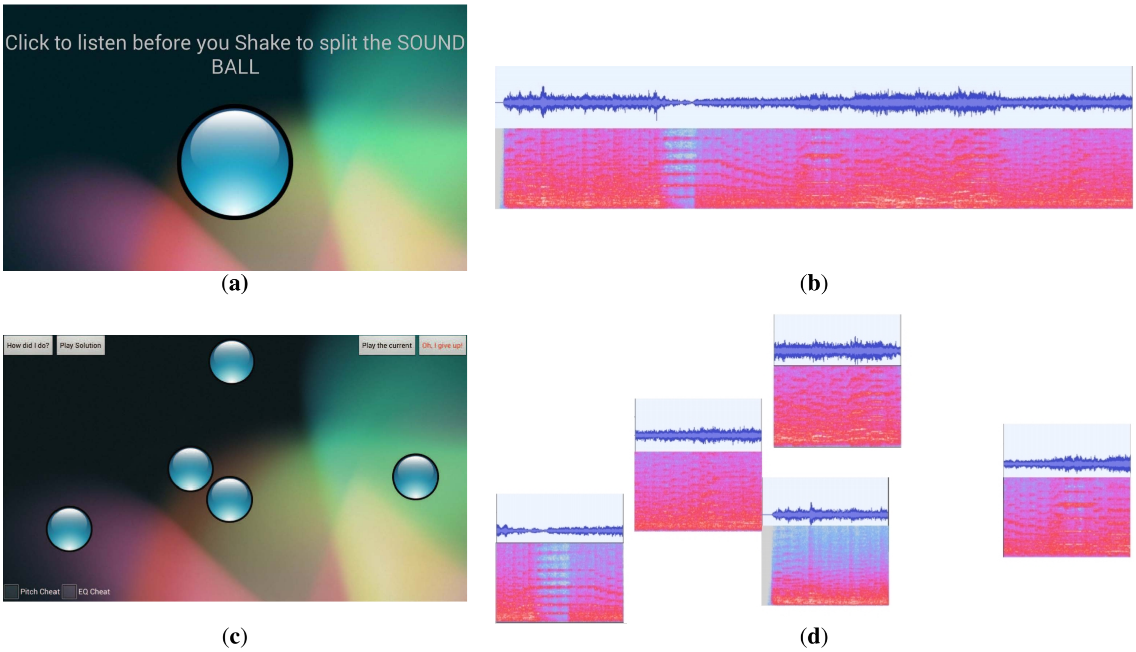

Figure 1. The *Music Puzzle* gameplay interface as seen on a tablet (left) and the waveforms and spectrograms of the sound objects (right). (**a**) Initiate a session, listen to the target music piece, and shake the tablet. (**b**) Waveform and spectrogram of the target music piece. (**c**) The "broken" sound, graphically represented by randomly placed circles. (**d**) Waveforms and spectrogram of the audio fragments (sound objects).

2.2.2 *The new design*

In the training, we redesigned the sound data from previous experiments. Furthermore, we changed the difficulty progression in the game from volitional to forced, according to the order shown in Table 1. We prepared four collections of increasing difficulty to play for four weeks, with one collection per week. Each collection contained four sets of recordings, and each set contained three types of sound materials of speech, music, and the mix of speech and music. In other words, during the training period the player could solve challenges from four collections of four sets, each containing three recordings, which gives a total of 48 puzzles to solve. It was allowed to repeat puzzles.

Difficulty levels were designed and defined using a combination of the number of created sound objects, characteristics and duration of the recording, cut-off frequencies of low- or high-pass filters, and the size of pitch shifts. The game is easier with fewer sound objects, wider filters, and bigger pitch differences. How challenging one finds the recorded sound in a specific puzzle is personally conditioned, but in practice it is easy to control this difficulty. Possible pitch changes in five steps and high/low-pass cut-off frequencies are listed in Table 1. For pitch changes, a higher difficulty is achieved using smaller transpositions. For timbre changes, lowering the low-pass cut-off and raising the high-pass cut-off will increase difficulty.

We chose four readings in Japanese from the copyright-expired collection of Japanese novels *Aozora-Roudoku*, a database similar to LibriVox. [2] Music recordings were chosen from the copyright-cleared RWC Music Database [17]. The third condition, a combination of speech and music, was achieved by simply mixing the recordings of reading and music. The recordings had durations of either eight or ten seconds, see Table 1.

From our experience, hearing habits of DHH persons are different from that of persons without hearing losses: The music that DHH usually prefer includes lyrics, and on a daily basis most listening is to speech. To "listen to music" is not their typical or top music-related activity, contrary to hearing persons [18]. To meet this concern and to give motivation for continued play, we used the three mentioned types of materials to involve more than instrumental music.

2.2.3 *The listening assessment procedure*

Since the music training with *MP* is not bottom-up but synthesized top-down, we do not express any intention of improving recognition of a specific music element such as melody with this training. The testing procedure for assessment of listening abilities that we prepared consisted of the following six items:

Dictation Both female and male voices with durations of 5.00s and 5.49s, respectively.

Beat recognition We used the BEAT test [19] to assess beat recognition. Altogether 55 beat patterns, of which 35 are from Povel and Essen [20], were proposed

[2] See `aozoraroudoku.jp` and `librivox.org`

Collection	*Set #*	*Fragments*	*Duration* (s)	*Transposition* (in cents)					*Filtering* (in Hz)	
				-2	-1	0	1	2	Low-pass	High-pass
1	1	3–5	8	—		0	—		—	
	2			—		0	—		—	
	3			-1020	-444	0	444	1020	—	
	4			—		0	—		3000	400
2	1	4–7	10	—		0	—		—	
	2			—		0	—		3000	400
	3			-1020	-444	0	444	1020	—	
	4			-1020	-444	0	444	1020	3000	400
3	1	5–8	8	-750	-390	0	390	750	—	
	2			—		0	—		1800	700
	3			-750	-390	0	390	750	1800	700
	4			-750	-390	0	390	750	1800	700
4	1	6–9	10	-750	-390	0	390	750	1800	700
	2			-500	-300	0	300	500	1000	1000
	3			-500	-300	0	300	500	1000	1000
	4			-500	-300	0	300	500	1000	1000

Table 1. Overview of the difficulty control in the experiment for four collections, each with four sets of three sound recordings. The number of sound objects created from the target recording was randomized for each game. Pitch was altered in five steps (value in cents), and timbre was changed through low-pass and high-pass filters (cut-off values in Hz).

to participants adaptively. Participants played with BEAT for 15 minutes at the longest.

Melody discrimination We used a part of an aptitude test by Gordon [21]. Participants answered by listening to fourteen sets of two melodies played by the piano: ten sets consist of two three-tone melodies, and four sets have more tones.

Environmental sound identification We proposed ten environmental sounds to identify in an open style described by Yuno et al. [22].

Preference to harmony We used a harmony test procedure from a previous experiment [3].

An easy game of *MP* We prepared an easy collection of speech, music, and the mix of them.

The time to complete the whole test was about thirty minutes.

2.2.4 Participants

Two participants were recruited for the experiment. *P1* is hard of hearing (male, 22y, 90dB hearing acuity), while *P2* is profoundly deaf (female, 23y, 115dB hearing acuity). They agreed to participate and the experiment was approved by the ethics committee of Tsukuba University of Technology. Besides music classes in elementary school and junior high school, both played the piano personally when they were elementary school students. P1 likes music very much and listens to music three hours a day. P2 likes music and listens to it for one hour per day. They both mostly listen to music with lyrics.

We planned the experiment with two reliable students because this experiment is conducted in an everyday life condition and not in a laboratory. The participants were instructed to play *MP* for a certain time per day (see below), but could play wherever and whenever it was convenient for them, just like they would play computer games outside the experimental scope. We argue that with this type of intervention and training it is appropriate to conduct the experiment in a delimited setting in order to get credible data and interpret the results from a known context; in the continuation, the design will be up-scaled to involve a larger number of participants.

2.2.5 Procedure

We asked the participants to use *MP* for at least thirty minutes a day, five days a week, with a scheduled minimum of ten hours playtime. [3] Each week they were given a new collection (1–4) with increasing difficulty. They were free to choose puzzles from any of the three material types in each set.

Participants finished the six-item assessment four times to reveal any effects of the training (Figure 2). One assessment was done before starting the training (pre-test), one after two weeks (finished Collections 1–2, Interim test), one after further two weeks (finished Collections 3–4, post-test 1), and one final two weeks after the training (post-test 2). The order of the six items in the assessment test was not decided – participants chose the order according to their moods and to avoid antipathy toward the test. In the instructions, the listed order of the test items was however the same for the four assessment instances. After the four-

[3] 0.5 hrs/day * 5 days/week * 4 weeks. Thirty minutes included game time and rest.

week training, participants filled in questionnaires. Before starting the training, participants were introduced to *MP* with material from past experiments and tried puzzles for acquainting with the game.

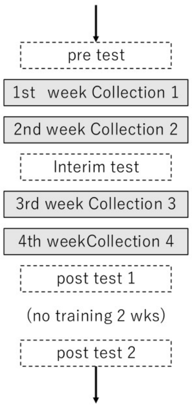

Figure 2. Procedure of the music training. During each training week, a participant used *MP* for at least 30 minutes a day, five days a week. Four instances of an assessments of hearing ability were scheduled: pre-test, interim test, and two post-tests.

3. RESULTS

3.1 *MP* training

Table 2 shows the number of games, average time to spend for each game (sec.), and the success rate (%) of each Collection (week) for the two participants. Both from time to spend for a game and the success rate, Collection 1 seems the easiest for the two participants.

Collection	*Games* P1	P2	*Time/game* (s) P1	P2	*Success rate* (%) P1	P2
1	55	43	112	195	96	79
2	30	23	155	384	97	61
3	23	36	163	227	83	19
4	13	42	208	195	85	19

Table 2. Results from playing *MP* for two participants during the four weeks in number of games played, average time per game in seconds, and success rate in solving the puzzle.

Figures 3 and 4 show the average time spent for each game and the success rate for each material type (speech, music, and the mix of speech and music) respectively. Judging from the time spent per game and the success rate, music was the most difficult condition for P1. Both music and the mix had a low success rate for P2 in Collections 3 and 4, and these collections also had a higher difficulty.

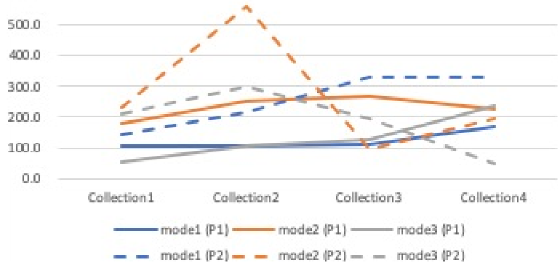

Figure 3. Average time (in seconds) per game spent for each mode (material types speech, music, mix) and participant (P1-2).

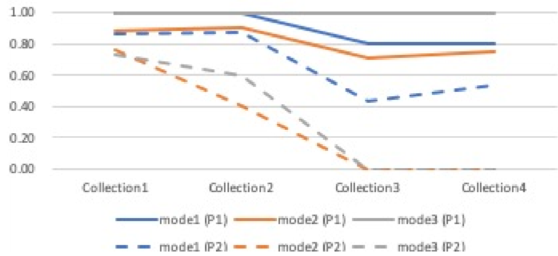

Figure 4. Success rate of solved games for each mode (material types speech, music, mix) and participant (P1-2).

3.2 Assessment

From the six test items (dictation, beat recognition, melody discrimination, environmental sounds identification, preference to harmony, a game of *MP*) that were included in the assessment which took place at four instances during the experiment, it was hard to tell the effect of the training:

Dictation Figure 5 shows the rate of correct syllables identified by P1 for the male and the female voice. P2 did not catch any words in the two readings.

Beat recognition P1 showed the better beat recognition with BEAT as the training proceeded.

Melody discrimination Figure 6 shows the success rate for melody discrimination.

Environmental sounds identification Figure 7 shows the identification rate for ten environmental sounds.

Preference to harmony This assessment does not have the correct answer but just to see the tendency of harmony preference. There were no specific differences in harmony preference before and after the training, nor specific preferences to performance which the melody and the accompaniment are played in the same key (the original performance).

A game of *MP* Since the game was designed to be easy, there were no specific differences in terms of playing time and success rate before and after the training.

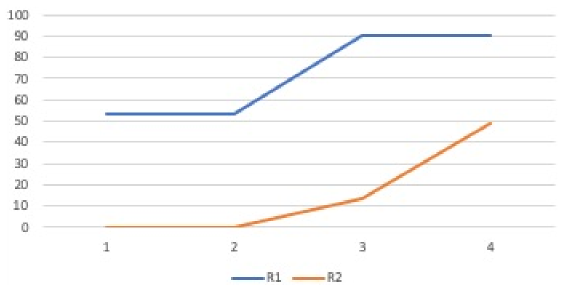

Figure 5. P1's correct rating of syllables in sentences (dictation). The upper line is sentences read by a male voice, the lower read by a female voice. (P2 did not catch any words in the two readings.)

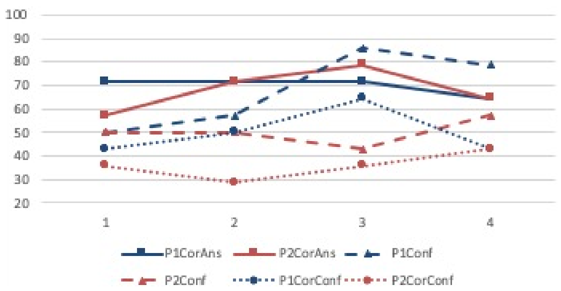

Figure 6. The success rate of melody discrimination for both participants. The bold lines show the success rate of correct answers, the dashed lines are their rated confidence, and the dotted lines show correct answer with a rated high confidence.

3.3 Subjective evaluation

Answers to inquiries related to *MP* and the assessment are shown in Table 3. Participants were also asked to rate along a five-graded scale (very easy, easy, so-so, difficult, very difficult). They felt music was the most difficult among the three material types. Pitch correction was difficult for both participants, while P1 stated that timbre correction was easy. In addition, they mentioned that:

> The concentration in playing *MP* is reducing in the final week. The increased number of sound objects made me feel that *MP* was difficult. [P1, translated from Japanese]

and

> I feel that I can get characteristics of sounds better and have acuter hearing. It was difficult to get sound cues in shorter length of sounds. Beat recognition was difficult. I could not recognize the difficulty level of melodic contour discrimination. [P2, translated from Japanese]

4. DISCUSSION

We could not determine any effect in relation to the conducted assessment from four weeks of music training with

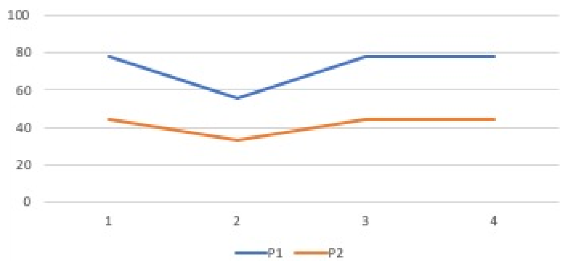

Figure 7. The success rate of correct identification for environmental sounds for both participants.

MP. Besides the difference in the level of hearing loss between the two participants, the differences of the frequency and voluntary listening to music between them may be the cause of the success rates during the training and the results of the assessment. Even considering the improvement of P1's dictation in the final test, it is hard to tell if it depends on the sentence memory for dictation or as a result of repetition. Among many possible reasons for these results, we will discuss (1) the assessment of the training, (2) the period and time of the training, and (3) the difficulty level of the training.

4.1 Assessment

There are a few assessment battery tests proposed to evaluate the capabilities of music perception for DHH persons. Roy et al. [23] measure music perception along the musical elements of rhythm, pitch, melody, harmony, and timbre by asking participants to judge whether sounds presented in pairs within one element are the same or not. It targets children with cochlear implants. Appreciation of Music in Cochlear Implantees (AMICI) [24] is a clinical test for music perception which assesses discrimination between music and environmental noise, musical instrument identification, musical style identification, and musical piece identification. AMICI was shown to be reliable as a clinical music perception test for cochlear implant users.

Our battery test consists of six kinds of tests ranging from speech, environmental sounds, to music as described in 2.2.3, with a holistic approach to sound recognition. Since the *MP* was used as a synthetic training method with three kinds of sound material – speech, music, and their combination – we employed a wide variety of test types. As a result, it is difficult to judge the effectiveness of such synthetic computer-based music training.

4.2 Period and Time

Music training for CI users in the study by Fuller et al. [15] amounted to twelve hours over six weeks (two hours per week). As mentioned in Section 1.2, they conducted two types of training: analytic computer-based and synthetic music therapy. Their battery test consisted of speech intelligibility in quiet and noise, vocal emotion identification, music contour identification (MCI), and quality of life. Analytic computer-based training caused an improvement in MCI. In their report, another music training of one

Playing *MP*		
Question	P1	P2
Did you find *MP* to be difficult?	so-so	difficult
Which sound type did you prefer?	speech	speech
Which sound type was most difficult?	music	music
Was it difficult to order sound objects?	so-so	difficult
Was it difficult to find correct pitch?	difficult	very difficult
— Which sound type was most difficult?	music	music
Was it difficult to find correct timbre?	easy	very difficult
— Which sound type was most difficult?	music	music
Assessment		
Question	P1	P2
Which test was most difficult?	beat recognition	dictation
Which test was easiest?	*MP*	harmony preference
Did difficulty increase during training?	so-so	yes

Table 3. Subjective evaluation of training with *MP* for each participant from responses to questions about both the *MP* and the assessment.

hour per week for six months (altogether almost twenty-four hours) was introduced. Although this training improved speech perception, the authors were skeptical about the training effects.

Our training time and duration amounted to a total of ten hours over four weeks (thirty minutes per day, five days per week). One conclusion is that a period of one month was too short to attain results from training. Despite this, we will not claim that simply having a longer training period necessarily will improve the results; the combination of the training time, regularity, and the battery test is also an important consideration to assess hearing abilities.

4.3 Difficulty level

Collections 3–4 seem to cause the two participants to struggle to play compared with Collections 1–2, as expected. As shown in Table 1, we prepared the third and the fourth collection with almost similar difficulty levels, but with smaller transpositions and more open filters. The fourth collection was also expected to be a bit more difficult in terms of having a higher number of sound objects for the participants to arrange. To address this assumption, we asked three hearing persons (2M/1F, ages 19–24) to participate in an experiment to validate the difficulty levels of the *MP* used in training. The results revealed that for them the third collection was somewhat more difficult. [4]

We believe that even when the difficulty level is not persistently increasing, the order of the puzzles have little practical consequence in contrast to the overall positive impact of participating in training. Nonetheless, the aim was to have an increasing difficulty, and this shortfall may have affected the results. In effect, we maintain that the material used for *MP* and training in general is a matter of importance.

[4] One can argue that, for instance, a transposition of 500 cents can be easier than one of 750 cents because of the resulting interval. This was not tested on DHH before the test.

4.4 Future work

We aim to provide a fun music environment for improving DHH persons' hearing abilities, and using the Music Puzzle is one conceivable starting point. We are currently testing other game designs as well. With regards to the three points discussed above, it is *MP*'s responsibility to maintain the interest of the players to assure that sufficient time and effort is being invested into the training. This needs to be done with a reasonable difficulty progression, appropriate sound material, and an attractive gaming experience. Any training program needs to acknowledge that different hearing impairments implicate different hearing capabilities and preferences. Thus, providing participants to choose their sound material is arguably an advantageous way increase training effects from using the Music Puzzle.

Acknowledgments

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