A case study to examine differences in pitch shift with and without hearing aids *

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1 Introduction

Pitch, an auditory sensation mostly associated with music and speech, has been studied and debated extensively over the years. At the same time, there is still very much that we do not understand regarding how the brain and the ears decode pitch. One area of research to help in understanding the basic mechanisms of pitch perception is to look at how cochlear hearing loss affects this qualitative auditory sensation.

In the current study, we are looking at a particular phenomenon of pitch caused by hearing loss, where the perception of pitch has been shifted. In this paper, we use the term pitch shift to define the sensation where a change in pitch is perceived compared to one's previous knowledge of the particular pitch. In terms of western musical keys, this means that the listener's perception of a particular note or a range of notes has shifted, for example, a B followed by a C may start sounding like a B flat, or two notes an octave apart do not sound the same when played consecutively. To those who have never experienced this sensation that affects the musically trained, it may be an absurd idea that your perception of pitch can change. However, such sensation of familiar pitches becoming 'out-of-tune' has been recorded through anecdotes by musicians with hearing loss on online forums [1], as well as memoirs of musicians, such as the pianist Sviatoslav Richter [2]. In the memoir, he talks of his experience of hearing notes sounding one or two semitones sharper or flatter, describing this sensation as his own auditory system needing tuning. As a result, both his career and mental health were affected greatly.

Over the years, pitch shift has been studied briefly together with diplacusis, where the ears hear two different pitches [3, 4, 5, 6, 7, 8]. The idea of pitch shift as a product of hearing loss was suggested in [4] where the psychoacoustic tuning curves of a participant with diplacusis measured at 1000 Hz has shifted to around 2000 Hz. A pitch matching task between the two ears revealed that the perception of 1000 Hz in the impaired ear has also shifted higher. More recent studies have examined the relationship between absolute threshold and diplacusis [8] and the ageing effect of pitch shift sensation with participants of absolute pitch [9].

The current study relies on the ability of relative pitch, a more widespread skill among musicians than absolute pitch. It is a case study of one participant with music experiences, and his perception of pitch with and without his hearing aids. Specifically, we want to answer the below questions:

- Is the participant's semitone deviations significantly different from normal hearing musicians' tuning results?
- Do hearing aids make a difference in the participant's ability to tune semitones?
- Do hearing aids make a difference in the participant's consistency of tuning semitones?
- Do hearing aids make a difference in the time it takes for the participant to tune semitones?

2 Methodology

2.1 Participant

The participant is a 72-year-old male with severe sensorineural hearing loss. He noticed his ears started to deteriorate in his early 50s, and needed hearing aids since then. He started noticing discrepancies in his pitch perception two years ago. In terms of his musical abilities, he obtained Grade 8 in piano from the Associated Board of the Royal Schools of Music (ABRSM) at 20 and has over fifty years experience in non-professional music performance in piano and violin, as well as singing in choirs.

The Grade 8 exam consists of an aural test that requires a high command of relative pitch. For example, one part of the test requires the examinee to

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sing the lowest part of a three-part phrase, identify the cadence at the end of a continuing phrase, as well as identifying the three chords forming the cadential progression [10]. It is also seen as a prerequisite for music study in tertiary level. For example, the entrance standards at the Royal Academy of Music accept Grade 8 from ABRSM as evidence of good musicianship and aural abilities [11].

At the time of the experiment, he wears the phonak naìda up III and has had an adjustment nine months ago. Figure 1 shows the participant's right ear PTC results, where the probe signal level is at 10 dB SPL above his auditory thresholds.

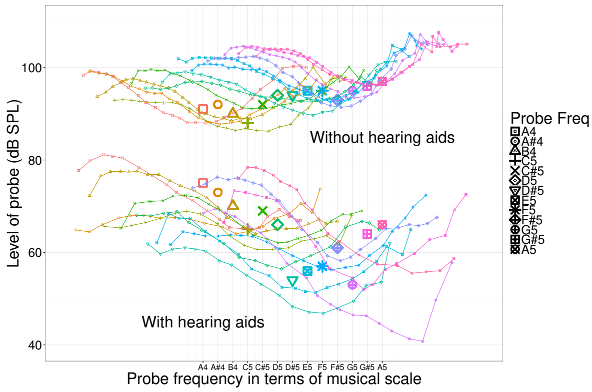

Fig. 1 PTC of participant with probe level at 10 dB SPL above his auditory thresholds

2.2 Test procedure

Two 300 ms tones a semitone apart are played alternately with a 300 ms gap and the participant judges whether or not the two tones are a semitone apart. A semitone equates to one twelfth of an octave. A semitone can also be represented by 100 cents, where cents are logarithmic units of measure used for musical intervals.

The tones are interpolated to be 15 dB SPL above the participant's hearing thresholds, which are different depending on whether he is wearing hearing aids or not. The two tones are always a semitone apart prior to any tuning. If the participant regards the distance between the two tones to be of a semitone, he presses the 'Enter' key to go on to the next note. If not, he will tune the tone in 20 cent steps until he is satisfied that the tones are a semitone apart. Once he presses the 'Enter' key, the next reference note will be a semitone above or below the previous reference note, avoiding any error accumulating to the next note.

Prior to the experiment, the participant is told that the two tones are a semitone apart and he is required to use his knowledge of a semitone to tune the note accordingly if he feels the interval does not sound like a semitone. The test goes for one octave from A4 (440 Hz) to A8 (880 Hz) in both directions. Each octave for a single direction takes approximately 5 minutes.

3 Results

The following section shows the results of the participant completing the tuning test three times with and without his hearing aids in the right ear.

3.1 Tuning accuracy

Tuning accuracy is measured by the amount of absolute deviation the interval is away from 100 cents, where 100 cents equal one semitone. Zero deviation means the interval is exactly one semitone apart, where 100 cent deviation indicates the two notes are tuned the same.

3.1.1 Comparisons with normal hearing musicians

Figure 2 shows the average cent deviation from the participant with and without hearing aids, as well as a normal hearing group of musicians, collected in a different study using the same experiment design [12]. Using Welch's t-test, we found that there is a significant difference between the cent deviation of the normal hearing musicians' group with the participant's without hearing aids data; t(106.28) = -7.02, p<0.01, as well as between normal hearing and the participant's with hearing aid data; t(93.8) = -8.21, p<0.01.

This suggests that the participant in our case study exhibits more unstable and incorrect tuning compared to his normal hearing counterparts, assuming his level of musicality (Grade 8 practical exam from ABRSM) would have allowed him to do previously.

3.1.2 Difference between wearing hearing aids and not

The mean cent deviation for the semitone tuning with hearing aids is 44.17 cent with 21.7 cent standard deviation. This is compared to 37.78 cent with 17.6 cent standard deviation for tuning deviation without hearing aids. Using a linear mixed effect analysis from the R package *lme4*, we found that there is a slight significant effect from the hearing

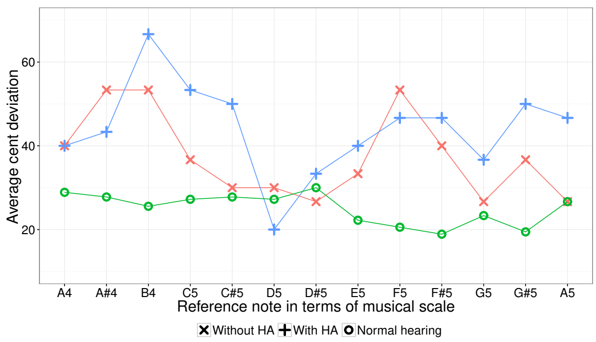

Fig. 2 Average cent deviation for tuning with and without hearing aids, and 8 normal hearing participants

aids $\chi^2(6) = 35.985$, $p = 0.049$. The fixed effects in the model were the musical notes, direction and hearing aids status, and we entered in trial as the random effect.

We can observe that the without hearing aids line tend to be lower and less spread out than the with hearing aid line. This means that without hearing aids, the participant is able to tune more accurately than without his hearing aids.

3.2 Consistency in tuning

The participant tuned the octave three times in both ascending and descending directions. This gave 24 semitone intervals with three repetitions. Consistency is measured by whether or not the participant is able to tune the interval with the same cent deviation each time. If the participant is able to tune the interval with same deviation all three times (trial 1's cent deviation is the same as trial 2's, which is also same as trial 3's), we consider the interval as completely consistent. If the participant is able to tune two times out of three the same, the interval is considered to be tuned partially consistent. Lastly, if all three trials gave three different cent deviation, the interval is considered to be tuned inconsistently completely.

Table 1 shows the number of semitone intervals that were tuned consistently all three times, partially consistently two out of three times (2/3), and inconsistently all three times (0/3).

Overall, the participant was able to tune more consistently without his hearing aids, where he can tune 23 semitone intervals at least partially consistently compared to only 19 intervals with hearing aids, and only one interval where he was completely inconsistent without his hearing aids, compared to

Table 1 Number of intervals being tuned consistently

	with HA	without HA
Completely consistent	1	3
Partially consistent	18	20
Completely inconsistent	5	1

5 intervals while wearing them.

3.3 Tuning time

The mean tuning time it took for the participant with hearing aids was 24.52 seconds, compared to 16.62 seconds without hearing aids. Using a linear mixed effect model analysis with the R package *lme4*, we found a significant effect from hearing aids $\chi^2(6) = 35.985$, $p < 0.01$. This shows that wearing hearing aids make the tuning longer to carry out, suggesting that the tones may be less clear while wearing hearing aids.

4 Discussion

The results suggests that there are differences in pitch perception and clarity between the participant wearing and not wearing hearing aids, at the same relative sound pressure level. However, one thing to consider is that the stimuli were presented to the participant over headphones both without hearing aids, as well as over his hearing aids. This could have caused unnecessary feedback for the participant, making the tones harder and less clear to hear, resulting in the less accurate, less consistent and slower response with the hearing aids. On the other hand, the participant reports listening to music with headphones over his hearing aids in daily life, making it a more familiar and easier task than listening through speakers.

In addition, we also did not check the hearing aid response and distortion via real ear measurement to verify the effects of average cent deviation. This means that we do not know whether the differences in some of the results were caused by inappropriate gain in the hearing aid, or a result of distortion at each filter boundary from overlapping.

Since using headphones over hearing aids may affect the gain at the ear, in future studies speakers or direct input to the hearing aids should be used when dealing with hearing aids.

5 Conclusions and Future work

Without hearing aids, our participant was able to tune more accurately, more consistently, as well as performing quicker tunings. This may be a result of the the way the experiment is set up, where the hearing aids were covered by a set of headphones during the experiment, causing unnecessary feedback and distortion. For future work, the experiment may need to be set up either via speakers, or directly feed the stimuli through the hearing aids.

Nonetheless, we are able to see through the current case study that the participant exhibits significantly different tuning results from normal hearing listeners, as well as different pitch perception with and without hearing aids, where headphones are used in daily life for music enjoyment.

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