The effect of symmetrical and asymmetrical hearing impairment on the music quality perception

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ABSTRACT

The purpose of this study was to investigate the effect of symmetrical, asymmetrical and unilateral hearing impairment on music quality perception. Six validated music pieces in the categories of classical music, folk music, and pop music were used to assess music quality in terms of its ‘Pleasantness’, ‘Naturalness’, ‘Fullness’, ’Roughness’ and ’Sharpness’. 58 participants with sensorineural hearing loss [20 with unilateral hearing loss (UHL), 20 bilateral symmetrical hearing loss (BSHL) and 18 bilateral asymmetrical hearing loss (BAHL)] and 29 normal hearing (NH) subjects participated in the present study. Hearing impaired/HI individuals had greater difficulty in overall music quality perception than NH individuals. Individuals with SHL rated music pleasantness and naturalness to be higher than participants with AHL. Moreover, the hearing threshold was negatively correlated to the pleasantness and naturalness perception in SHL and BAHL participants. HI subjects rated the familiar music pieces higher than unfamiliar music pieces in the three music categories. Music quality perception in participants with hearing impairment appeared to be affected by symmetry of hearing loss, degree of hearing loss and music familiarity when they were assessed using the music quality rating test/MQRT. This indicates that binaural symmetrical hearing is important to achieve a high level of music quality perception in HI listeners. This emphasizes the importance of provision of bilateral hearing assistive devices for people with asymmetrical hearing impairment that can compensate for differences in hearing loss between ears.

Key Words:

music quality; hearing impairment; binaural hearing; symmetry; asymmetry

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INTRODUCTION

People most often listen to music for their own enjoyment and music is generally expected to sound pleasant. Music quality perception is associated with people's ability to hear, process and understand subtle changes that correspond to music features [1, 2]. Therefore, normal hearing (NH) sensitivity is one of the essential factors for music quality perception, which enables listeners to achieve an understanding and appreciation of music by recognising and interpreting musical features (e.g. timbre, melody and pitch)[3-10]. Music quality perception requires accurate perception of sound temporal envelope and energy spectrum of its frequency components. Therefore, preserving normal hearing sensitivity can help listeners to extract the fine frequency and temporal information from the music pieces.

In contrast, for people with hearing impairment, evidence indicates that their musical perception is significantly damaged due to the reduced ability to fully utilize temporal fine structure and poor frequency selectivity [11]. For example, Leek and Summers [11] reported that the pitch of complex sound or music was distorted for people with sensorineural hearing loss. This poor pitch perception was expected to be directly correlated to listeners' reduced frequency discrimination and selectivity abilities, which was attributed to broadened auditory filters. Another important factor is temporal resolution processing, which relies on both analysis and comparison of the time pattern within each frequency band and affects the pitch perception based on exact timing of neural synchrony firing. Therefore, as a consequence of auditory filter and neural firing anomalies, poor frequency and temporal resolution, it is generally accepted that ability of music perception is affected in hearing-impaired (HI) subjects [7].

Studies by Most et al. [12] and Noble and Gatehouse. [13] investigated the improvement of sound perception by fitting hearing aid devices after hearing impairment. Recently, it seems clear that bilateral hearing setting has advantages over unilateral hearing fitting [12-15]. These studies have provided increasing support for the evidence that bilateral symmetrical hearing benefits speech recognition and sound localization in noisy environments when compared with asymmetrical hearing [16-18]. The mechanism behind binaural hearing advantage is mainly due to the combined effects of binaural redundancy, head shadow and binaural squelch, which can contribute to a signal to noise ratio (SNR) improvement of 8 dB by attenuating the interfering sound on the side of the target sound [17, 18].

Several researchers have compared music quality rating performance in subjects with different binaural hearing conditions, aiming to explore the symmetrical hearing effect on music quality perception [12, 13, 19]. However, the results obtained from these studies showed inconsistent effects. For example, Noble and Gatehouse [19] found better performance of music quality rating in 103 participants with symmetrical hearing loss when compared with 50 participants with asymmetrical hearing loss using a Speech, Spatial and Qualities of Hearing Scale. In contrast, the study by Most et al. [12] reported that no advanced binaural hearing benefit was found in music quality between bilateral and unilateral hearing aids users using the same assessment. The discrepancy of effect of symmetry of hearing loss on music quality obtained from different studies may be due to less reliability of this music quality rating test, which was conducted only by asking the subjects to recall their experience of music quality without actually listening to specific songs and it may cause a degree of bias.

In addition, various factors influence music quality perception, such as listening habit, individual music preference, and listening situation [1, 20]. In an earlier study, Cai et al [1] adapted a music quality rating test by Looi et al. [20] that provides a standard method for music quality rating and takes the variability of participant's listening habits into account. This method was found to be an effective method for testing Chinese NH individuals. Furthermore, the study by Cai et al. [1] found familiarity to be an important factor with regards to sound quality of music.

In order to further understand music quality perception in HI people, the present study compared the music quality perception in HI individual with different binaural symmetrical conditions (i.e., unilateral, bilateral symmetrical, and bilateral asymmetrical hearing losses). In addition, the music quality differences in terms of pleasantness, naturalness, fullness, roughness and sharpness were also compared between HI and NH individuals when using Chinese MQRT, which would indicate its effectiveness used in HI people. The outcome will contribute towards better understanding of the influence of audiometric configurations on music quality perception, and consequently facilitate further development of strategies for improving the music quality perception in HI people.

MATERIALS AND METHODS

Participants

Twenty-nine NH participants between 28 to 45 years of age and fifty-eight participants with sensorineural hearing loss between 25 to 48 years of age were recruited, including 20 with unilateral hearing loss (UHL), 20 with bilateral symmetrical hearing loss (BSHL) and 18 with bilateral asymmetrical hearing loss (BAHL). All participants were recruited via advertisements from either ENT/Audiology clinics (subjects with sensorineural hearing loss) or staff and students (NH subjects) at the Sun Yat-sen Hospital, China. Written consent was obtained from all participants before proceeding with any of the study procedures.

A clinical and audiometric assessment was performed. The clinical history included onset and duration of hearing loss, together with history of audiological rehabilitation. Although HI participants had various hearing loss either on one side or both sides, none of them had any experience with using hearing aids before being involved in this study. Professional musicians and subjects having regular musical training of more than two years were excluded from this study.

A summary of participant details is provided in Table 1. The audiometric threshold of the HI participants ranged from mild to moderately severe sensorineural hearing loss, i.e., no hearing threshold was worse than 70 dB HL at 500, 1000, 2000 and 4000 Hz in any ear. In the present study, the definitions of “symmetrical hearing” and “asymmetrical hearing” were adapted from the study by Noble and Gatehouse [19], i.e., symmetrical hearing is defined as an interaural difference of less than or equal to 15 dB in the thresholds averaged at 0.5 to 4 kHz, while asymmetrical hearing is defined as an interaural difference of more than 15 dB in the thresholds averaged at 0.5 to 4 kHz. Participants were excluded from this study if they had an air-bone gap larger than 10 dB at one or more frequencies on a pure tone audiogram. All the NH and HI participants were also required to have a type A tympanogram bilaterally.

Please insert Table 1 near here

Materials and experiment procedure

The musical materials and experimental procedures were adopted from a previous study [1]. In summary, six validated music pieces were used for the music quality rating test (MQRT) based on the highest percentage difference in familiarity levels and paired as 'familiar music piece' and 'unfamiliar music piece' in the categories of Classical music, Chinese folk music and Chinese pop music (for detailed information, please refer to the study by Cai et al. [1]). Meanwhile, all the music pairs were identified as sharing a similarity on the rhythm, tempo and frequency spectrum. They were:

- Classic music: "Serenade 'Eine kleine Nachtmusik, K525, 1st movement'" Mozart (familiar music) and "Concerto in D major K.218 Allegro" Mozart (unfamiliar music)
- Chinese folk music: "Jasmine flower (茉莉花)" (familiar music) and "Missing lover (想郎)" (unfamiliar music)
- Chinese pop music: "You don't have to say goodbye (大约在冬季)" (familiar music) and "Winter rain (冬雨)" (unfamiliar music).

The music quality rating scale is a continuous measurement, consisting of five music quality dimensions, i.e., 'pleasantness', 'naturalness', 'fullness', 'roughness' and 'sharpness', which were adapted from the previous studies[20-27]. Figure 1 demonstrated the 'pleasantness' and 'naturalness' dimensions ranging from 'unpleasant' to 'pleasant' and 'unnatural' to 'natural' with equivalent scores from 0 to 10 respectively. In contrast, the other three dimensions (i.e., fullness, roughness and sharpness) were assessed with mid-point scales (MPS) from a minimum value of -5 to a maximum value of 5. All the participants were informed that they can rate real number for each rating scales.

Please insert Figure 1 near here

An 8 Gb Apple iPod MP3 player (Apple Inc., USA), together with headphones (Beyerdynamic DT 880 Pro) was used to deliver the pieces of music. The listening level was set up at approximately 40 dB above the hearing thresholds of the better ear for each participant initially. However, considering the potential risk of causing hearing damage and sound distortion, initial listening level never exceeded 80% of volume bar (equivalent to approximately 85 dBA) for participants with moderate to moderately severe hearing impairment. All participants were requested to adjust to individual comfort listening levels when they listened to each music piece.

All participants were given full instructions as well as being asked to practice by listening to musical training pieces representing different music quality dimensions in order to familiarise themselves with the music quality dimensions, and consequently improving the reliability and accuracy of the tests. For example, the musical training piece for the sharpness scale was selected in terms of the degree of high frequency components, which enabled participants to identify and understand the dimensions of the dullness and sharpness scales. Before formally performing the MQRT, participants were required to assess the familiarity level of the six music pieces based on the familiarity assessment questionnaire [1].

Data analysis

The data was analysed using SPSS version 16.0 to perform parametric and non-parametric tests. Repeated-measures analysis of variance (RM-ANOVA) was conducted to examine the effects of the following factors: symmetry of hearing loss (NH, UHL, BSHL and BAHL groups), music familiarity (unfamiliar and familiar) and category (classical, folk and pop music) on the rating scores of the music pleasantness, naturalness, fullness, roughness and sharpness dimensions. The familiarity and category effects were chosen for statistical analysis because previous research showed that these two effects might influence the music quality rating in NH and HI subjects[1, 20, 28]. Moreover, Pearson tests were separately used to explore the relationship between hearing thresholds and music quality rating in HI participants, respectively. A *p* level of less than 0.05 was considered statistically significant.

RESULTS

Demographic data and hearing thresholds among the groups

Table 1 shows general information for participants, including gender ratios, mean and standard deviation for age, and hearing levels of the better and worse ears. A Chi-squared test and a one-way ANOVA were performed to analyze the gender and age differences respectively among the NH, UHL, BSHL and BAHL participants. No significant differences were found.

Comparison of music quality rating between subjects among NH, UHL, BSHL and BAHL groups

For the purpose of identification of the familiarity effect on music quality rating, the music familiarity assessment was performed before the MQRT [1]. All the participants were required to listen to all music pieces, and they consequently rated the familiarity level of each music piece by choosing one of the following three options:

A. I definitely know this music piece;

B. I may have heard this music piece before, but I am not sure;

C. I definitely do not know this music piece.

As a result, all the participants rated the familiarity level of each music piece consistent with the previous results [1], i.e., the participants that definitely knew the familiar music piece at the familiar level chose ‘Definitely know the song’, and chose the paired unfamiliar music piece regarded as ‘unsure’ or ‘Definitely unknown the song’ in the familiarity assessment.

The effects of hearing impairment on music quality perception were explored when comparing the quality ratings between each group. RM-ANOVA on the pleasantness rating showed the significant effects of symmetry of hearing loss ($F(3,83)=28.41$, $p<0.001$) and music familiarity ($F(1,83)=79.61$, $p<0.001$). A significant interaction was also found between music category and symmetry of hearing loss ($F(6,166)=2.53$, $p=0.023$) which led to a separate music familiarity × symmetry of hearing loss ANVOA analysis for each category. Significant greater pleasantness rating for NH participants compared with the other three HI groups (i.e., UHL, BSHL and BAHL) was observed for classical music ($F(3,83)=22.83$, $p<0.001$), folk music ($F(3,83)=14.72$, $p<0.001$) and pop music ($F(3,83)=17.67$, $p<0.001$) (See Figure 2). Moreover, significant differences were found between UHL and BAHL in all three music categories and between BSHL and BAHL in classical ($p=0.012$) and pop music ($p=0.023$). Even though there was no significant difference in folk music, the ratings on the pleasantness scale were higher for BSHL group than BAHL group (See Figure 2).

Please insert **Figure 2** near here

A separateRM-ANOVA was also performed for the naturalness rating for each music category. The results revealed a significant effect of symmetry of hearing loss ($F(3,83)=42.12$, $p<0.001$) and significant interaction between music category and symmetry of hearing loss ($F(6,166)=3.34$, $p=0.004$) (Figure 2). Similarly, there was a significant difference between the NH group and the three HI groups for each music category. In addition, significant difference on the naturalness rating was found between the BSHL and BAHL groups for classical music ($p=0.013$) and pop music ($p=0.020$).

In addition, because the ‘0’ point of the fullness, roughness and sharpness rating scale meant perfect sound quality for the music piece, the distance between the rated value and the ‘0’ position indicated distance from perfect sound, regardless of whether the values were positive or negative. Therefore, the absolute values of the fullness, roughness and sharpness ratings were used for the analysis. Figure 3 shows the group mean values of the fullness, roughness and sharpness ratings in the categories of Classical, Folk, and pop music for NH and HI individuals. For fullness rating, significant effect was only found in symmetry of hearing loss ($F(3,83)=6.35$, $p=0.01$). A Bonferroni-adjusted comparison demonstrated that fullness rating was significantly poorer for BAHL group than for NH ($p<0.001$) and UHL ($p=0.021$) groups.

Roughness rating revealed significant differences in symmetry of hearing loss ($F(3,83)=9.07$, $p<0.001$) and familiarity factor ($F(1,83)=4.51$, $p=0.037$) as well as significant interaction between category and symmetry of hearing loss ($F(6,166)=2.61$, $p=0.019$), which led to a separate RM-ANOVA for each category. As Figure 3 shows, a significant difference of symmetry of hearing loss was found in classical ($F(3,83)=8.01$, $p<0.001$) and pop ($F(3,83)=12.04$, $p<0.001$) music. Further Bonferroni-adjusted analysis showed that roughness perception was rated significantly poorer in BAHL group than NH ($p<0.001$) and UHL ($p=0.002$) groups in both classical and pop music.

Sharpness perception, RM-ANOVA showed significant difference in symmetry of hearing loss [$F(3,83)=3.70$, $p=0.015$], music familiarity [$F(1,83)=11.27$, $p=0.001$] and significant interaction of category x familiarity x symmetry of hearing loss [$F(6,166)=3.41$, $p=0.003$]. Therefore, separate one-way ANOVA was performed for each music piece. Significant difference in symmetry of hearing loss was found in familiar classical music [$F(3,83)=3.79$, $p=0.013$], unfamiliar classical music [$F(3,83)=4.37$, $p=0.007$] and familiar pop music [F(3,83)=18.05, p<0.001]. Following Bonferroni-adjusted comparison noted that significant poorer rating in sharpness perception was found in BAHL group than other three hearing groups in familiar classical music [BAHL vs NH, UHL, BSHL (p=0.048, =0.047, =0.022)], unfamiliar classical music [BAHL vs NH, UHL (p=0.030, =0.006)] and familiar pop music [(BAHL vs NH, UHL, BSHL (p<0.001, <0.001, =0.001) (see Figure 3).

Please insert Figure 3 near here

Correlations between hearing thresholds and music quality rating in HI groups

The correlations between the hearing thresholds of the better as well as the worse ear and the five mean qualities rating of the six music pieces in HI groups were conducted. The pleasantness and naturalness negatively correlated significantly with the better ear and the worse ear in the BSHL group (better ear: r_p=-0.678, p=0.001; worse ear: r_p=-0.710, p<0.001, Figure 4a; better ear: r_n=-0.595, p=0.006; worse ear: r_n=-0.535, p=0.015, Figure 4b). While significant correlation between quality perception (both pleasantness and naturalness) and hearing thresholds of the better ears was found in the BAHL group (r_p=-0.774, p<0.001; r_n=-0.752, p<0.001, Figure 4c). However, no significant correlation between hearing thresholds of the worse ear and music quality rating was observed in the BAHL group (pleasantness: r=-0.362, p=0.140; naturalness: r=-0.106, p=0.674, Figure 4d) and in UHL group (pleasantness: r=-0.155, p=0.515; naturalness: r=-0.437, p=0.06). There were no significant correlations between hearing thresholds and fullness, roughness or sharpness ratings for any of the HI groups (UHL, BSHL and BAHL).

Please insert Figure 4 near here

DISCUSSION

The effect of hearing impairment on music quality perception in general

Significantly reduced music quality ratings were found in participants with various hearing impairment using a music quality rating test. In the present study, HI participants rated music quality perception lower than NH participants in terms of pleasantness and naturalness in classical music, folk music and pop music as well as fullness, roughness and sharpness in pop music. These results are consistent with the findings of Leek et al. [29] who found music pieces were rated as less pleasant and distorted for HI listeners.

Music quality perception is closely related to the accuracy of music timbre perception, which requires listeners to perceive both the music temporal envelope as well as the frequency spectrum of harmonic components [25]. According to the tonotopic theory, the cochlea breaks down sounds according to its frequency content and sends them up to the primary cortex [30]. These frequencies are multiples of a common fundamental frequency (F0), which form the perception of pitch. For the HI subjects, a significant sensorineural hearing impairment would lead to reduced frequency selectivity and spectrum discrimination [31]. Moore has suggested that the filter bandwidths generally increased when the hearing loss increased above 25 dB [31]. Moreover, the bandwidths can reach twice the values of normal hearing when hearing loss reached about 40 to 50 dB. These results have revealed that auditory filters in HI subjects are often broader than in NH people and consequently hearing impairment restricts pitch perception and appreciation. It is interesting to note that hearing threshold is correlated to music quality perception in HI listeners. In the present study, the results indicated that music pleasantness and naturalness were negatively correlated with the pure tone average of both ears in BSHL and the better ear in BAHL listeners, which suggests that music quality perception is related to the degree of hearing loss of the better ear.

The effect of symmetrical and asymmetrical hearing impairment on music quality perception

Current participants with BSHL had superior performance in the music pleasantness and naturalness than participants with BAHL, which is consistent with previous studies [14, 17, 32]. Balfour and Hawkins [32] showed a binaural symmetry advantage in terms of the music quality perception in HI people fitted with binaural hearing aids than those fitted with monaural hearing aids. Moreover, they found significant binaural preference in overall impression, fullness and spaciousness ratings associated with binaural listening. Noble and Gatehouse [19] further pointed out that binaural symmetry of hearing surpassed the asymmetry of hearing group not only in terms of sound qualities, but also spatial localization and speech in noise, these improvements were due to the combination binaural effects [17]. For example, binaural summation enables an enhanced sensitivity to small changes of intensity and frequency that contribute to improved discrimination of sound qualities or speech [33].

However, there were non-significant differences in terms of fullness, roughness and sharpness between the BSHL and BAHL groups. The possible reason may lie in the fact that the difference between symmetry of hearing and asymmetry of hearing is not able to be detected in these specific dimensions when evaluating the music quality perception. For example, Blauert and Hawkins [32] suggested that binaural symmetry of hearing has weak advantages in some specific music quality dimensions, such as smoothness, and brightness.

In the present study, the hearing thresholds of the better and the worse ears from BSHL participants as well as the better ears from BAHL participants were negatively correlated to the pleasantness and naturalness perception. This indicates that perceived quality of music is likely to be related to the audiometric threshold of the better ear. Better audibility in the ear may play the major part to the sound perception, listeners may well adapt to altered interaural intensity and frequency difference between the better and worse ear, and possibly learn to determine and discriminate sound quality [13]. However, it is noteworthy that people with UHL had lower pleasantness and naturalness ratings than NH people in the present study, although they had normal hearing thresholds in the better ears. This finding is consistent with the study by Dwyer et al. [14], who found NH subjects outperformed UHL subjects in terms of sound quality, spatial localization and speech in noise. A lack of binaural symmetrical hearing in people with UHL may be an important factor contributing for the poor music quality perception [14].

Familiarity effect on music quality perception

In the present study, significant differences in music quality rating between familiar and unfamiliar music pieces were found in HI subjects. Listeners rated familiar music significantly higher in pleasantness than unfamiliar music for each music category. This effect seemed associated with the subjects' experience of listening to music [34]. For example, Peretz et al. [34] suggested that music enjoyment was improved by listening to a familiar music piece or by repetitively being presented with a music piece. This suggestion was further supported by a recent neurophysiological study, which identified the music familiarity effect on listeners' pleasure experience by revealing increased hemodynamic activity and positive correlation with sympathetic nervous system activity [35]. Therefore, on the basis of the results derived from the present study, the familiarity effect seems to be beneficial for improving their music quality perception in people with hearing loss, and listening familiar music should be considered as a part of initial aural rehabilitative strategy to help improving music enjoyment.

CONCLUSION

There were significant decreases in music quality perception in terms of pleasantness, naturalness, fullness, roughness and sharpness rating among the HI participants in comparison with NH participants when using the MQRT. Music quality perception in participants with hearing impairment appeared to be affected by degree of hearing loss, symmetry of hearing loss and music familiarity when they were assessed using the MQRT. Adverse effect of degree of hearing loss was found on the pleasantness and naturalness rating in BSHL and BAHL participants. In addition, subjects with BSHL rated classical and pop music as more pleasant and natural than subjects with BAHL. These indicate the importance of binaural symmetrical hearing for music quality perception in HI listeners, such as providing bilateral hearing assistive devices for people with asymmetrical hearing impairment in order to improve the binaural balance and compensate for differences in hearing loss between ears. Furthermore, significantly better pleasantness and sharpness ratings for familiar music were found in all HI patients. This result suggests that listening to familiar music should be considered as a part of initial aural rehabilitative strategy to improve their music quality perception.

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Figure Legends

Fig.1 The rating scales in the music quality rating test. (Adapted from Cai et al. 2013)

Fig.2 Comparisons of music pleasantness and naturalness perception in normal hearing subjects and HI subjects with different audiometric configurations. *Note:* * there was a significant difference at $p<0.05$. * in green bar indicated significant difference between NH group and other three hearing groups. "NH, UHL, BSHL and BAHL" represent normal hearing, unilateral hearing loss, symmetrical hearing loss and bilateral asymmetrical hearing loss, respectively

Fig.3 Comparisons of music fullness, roughness and sharpness perception in NH subjects and HI subjects with different audiometric configurations. *Note:* * there was a significant difference at $p<0.05$. "NH, UHL, BSHL and BAHL" represent normal hearing, unilateral hearing loss, symmetrical hearing loss and bilateral asymmetrical hearing loss, respectively

Fig.4 Correlations between hearing thresholds and music quality ratings in BSHL and BAHL groups