The Effect of Hearing Aid Amplification on Pitch Salience

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ABSTRACT

While hearing aids are optimized for listening to and hearing speech in noisy environments, there are still many challenges when using hearing aids to listen to music. Hearing aids may not necessarily mimic the nonlinear processing performed by the cochlea in normal hearing. This could mean that hearing impaired individuals do not perceive music the same way a normal hearing person would. When two musical tones are played simultaneously at equal presentation levels, the tone with the higher frequency will be perceived as more salient for a normal hearing person. This study examined how different types of hearing loss affect the neural pitch salience profile obtained with a computational model of the auditory periphery. To measure how effective the hearing aid amplification was at improving the neural pitch salience profile, each result was compared to the neural pitch salience profile of an unaided normal hearing ear.

The results show that less severe hearing loss types tend to have pitch salience profiles closer to normal after hearing aid amplification. This can be well modeled as a linear relationship unless noise reduction is added to the simulation. For each different type of hearing loss there appears to be a trade-off between the ability of the upper tone and the lower tone to match normal hearing performance. Also of interest is that the conditions that yield the smallest and largest errors seem to be consistent across hearing loss types and methods of hearing aid processing. This study provides a starting point to improve hearing aid processing for music perception.

INTRODUCTION

The high voice superiority effect is the phenomenon in which the higher of two tones played simultaneously will be more perceptually salient, even if the two tones are equally loud (Trainor et al., 2014). In this study we used the approach of Trainor et al. (2014), in which a neural model from Zilany et al. (2014) is used to predict pitch salience following the method shown in Fig. 1.

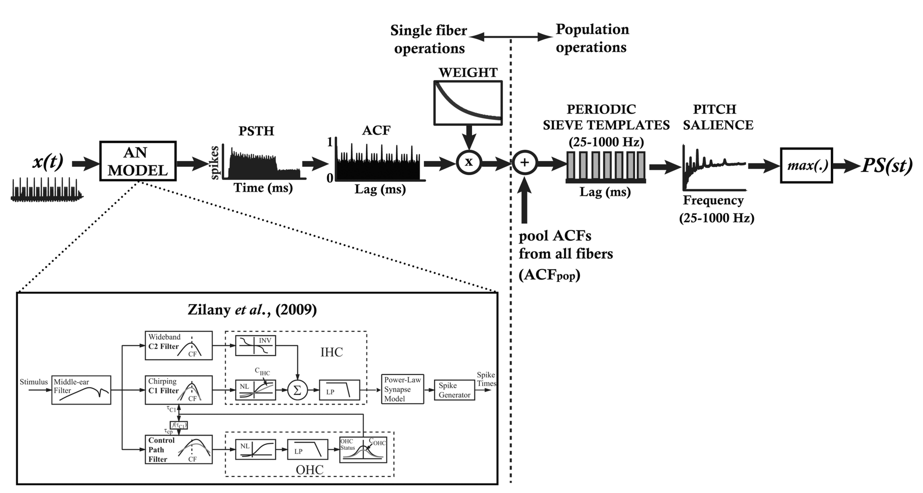

Figure 1: Procedure for computing neural pitch salience from AN responses to musical intervals (Bidelman and Heinz, 2011).

The experiments and modeling in Trainor et al. (2014) and Bhatt (2013) only considered normal hearing individuals. Many hearing impaired listeners also enjoy music either by playing an instrument or listening to performances and may require hearing aids to do so. In Bidelman and Heinz (2011) they found that the pitch salience with hearing loss was similar to normal hearing but the peaks were reduced.

PIANO TONE SIMULATIONS: METHODS

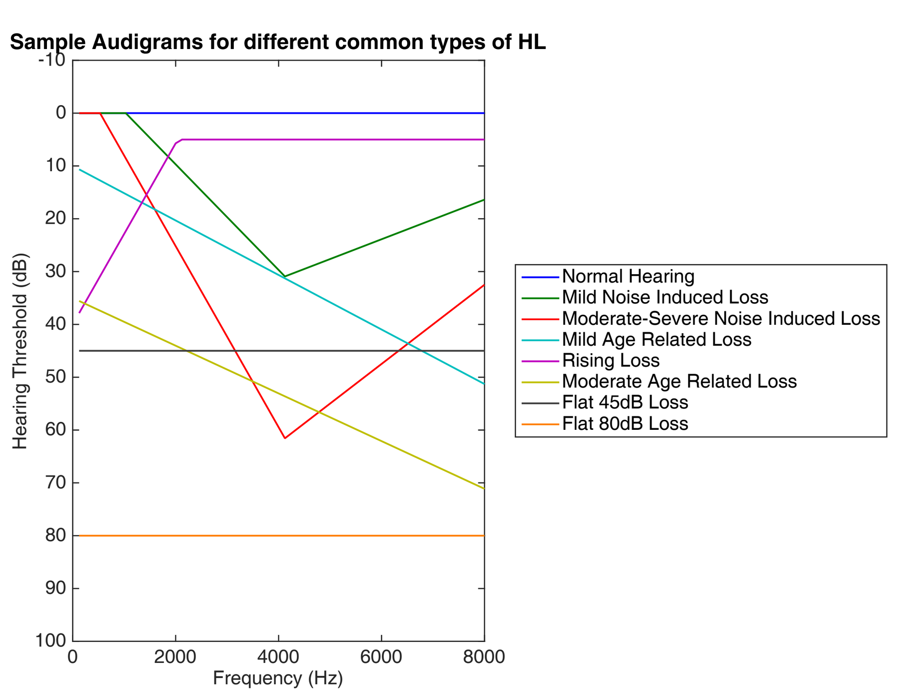

Figure 2: Sample audiograms used in the computer simulations.

The hearing loss audiograms used in the simulations are shown in Fig. 2 These audiograms match audiograms from Bradley (2007).

Additional stimulus parameters are modified from simulations in Bhatt (2013) to better represent the range of musical instruments.

- The upper tone sound pressure level (SPL) is always 67.5 dB SPL while the lower tone SPL is 57.5, 67.5 or 77.5 dB SPL.
- The lower tone frequency is 65, 130 or 261 Hz.
- The upper tone frequency changes from the lower tone frequency to 2,092 Hz in quarter semitone steps.
- The spectral tilt of all tones is −6 dB/octave to match typical instrument harmonics.
- The hearing aid amplification is either NAL-R (linear) or DSL with WDRC (nonlinear).

To examine the effect of additional hearing aid processing, an analog-to-digital converter (ADC) and simple noise reduction (NR) filter were added to the simulations based on descriptions in Dillon (2012).

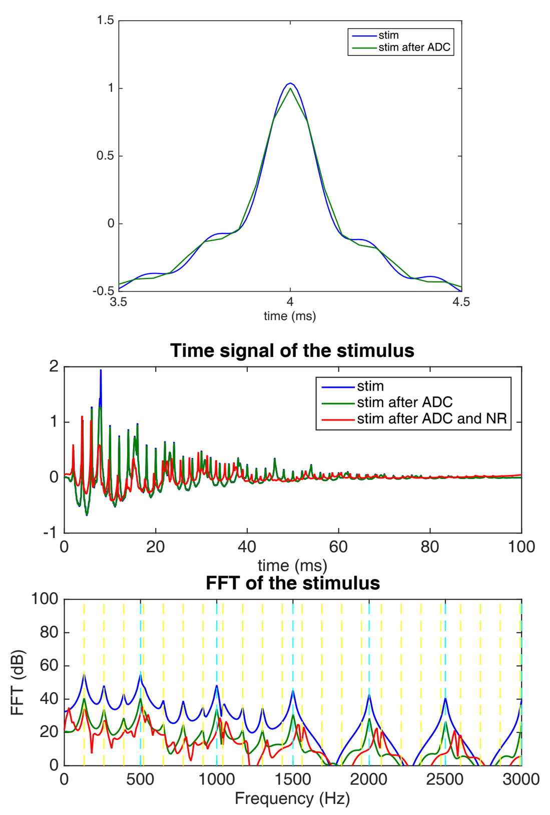

Figure 3: A sample of how the ADC and NR filter affect a pair of simultaneous piano tones at 130 and 500 Hz, both at 77.5 dB SPL. Harmonics for the low and high tone are shown in yellow and cyan respectively.

As illustrated in Fig. 1, the neural pitch salience is calculated using a periodic sieve analysis of the population-level autocorrelation function (ACF_{pop}) (Bidelman and Heinz, 2011; Trainor et al., 2014). ACF_{pop} is a weighted sum of the ACF of the poststimulus time histograms (PSTH) for each fiber. For each fundamental frequency the sieve template consists of bins at the fundamental frequency and its multiples. Neural pitch salience is the density of ACF_{pop} that fall within the sieve bins divided by the mean density of the whole ACF_{pop} distribution. Example results are shown in Fig. 4 for a low-frequency tone of a fixed frequency and a varying high-frequency tone.

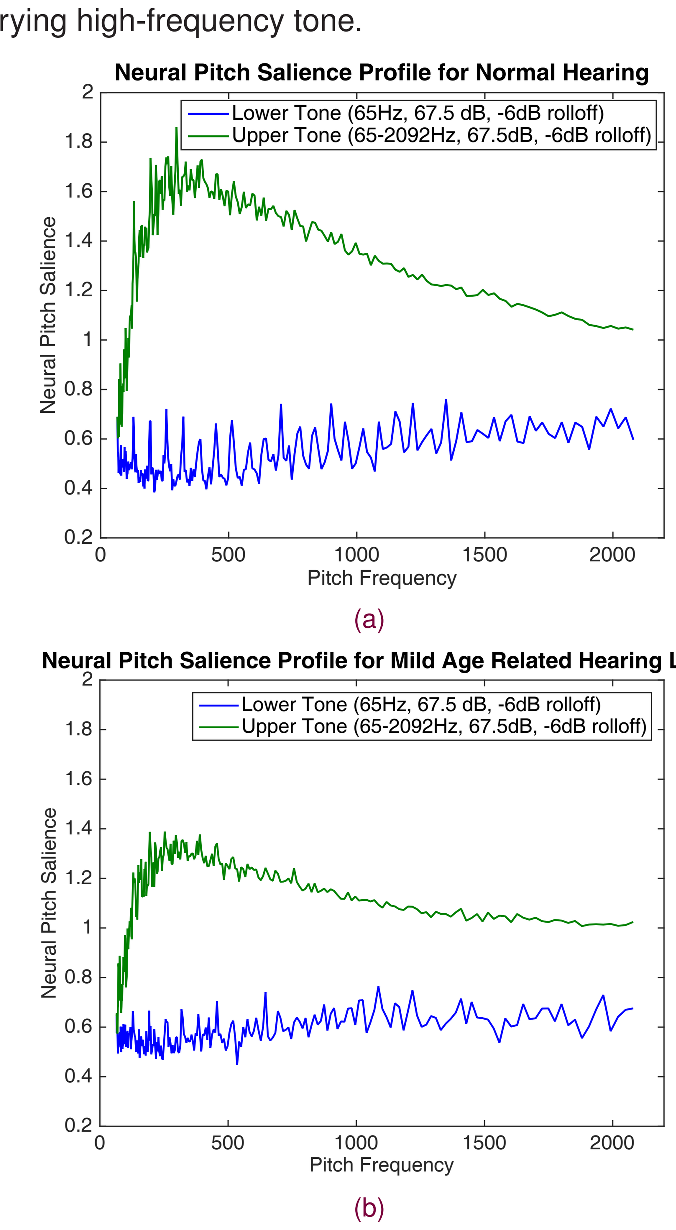

Figure 4: Sample neural pitch salience profiles for (a) normal hearing and (b) a mild age related hearing loss.

PIANO TONE SIMULATIONS: RESULTS

Each neural pitch salience profile was compared to the unaided normal hearing ear and the mean-squared errors (MSEs) calculated. The MSE was found to increase with the degree of hearing loss in general. Therefore, we performed a linear fit between MSE and H3fa (an average hearing loss using 3 frequencies), as shown in Fig. 5.

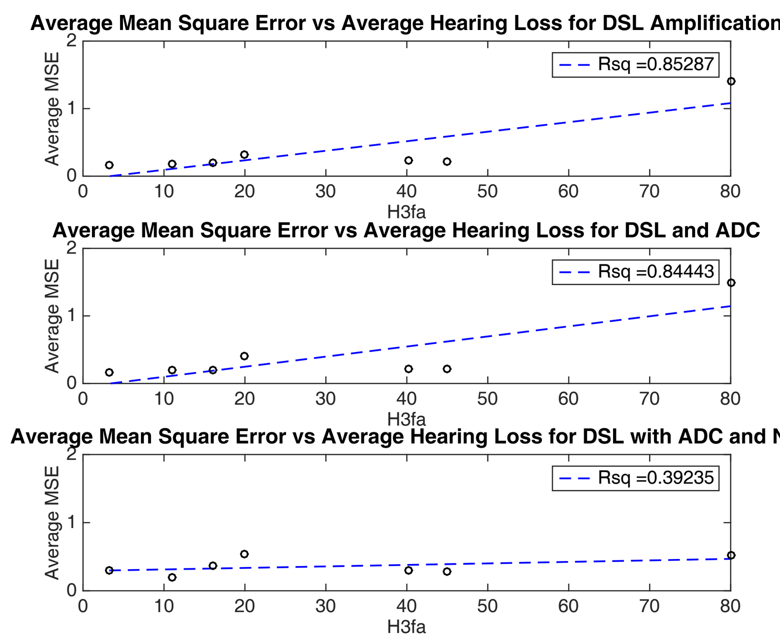

Figure 5: Average MSE in neural pitch salience for DSL hearing aid versus 3-frequency average hearing loss.

The resulting mean square errors (MSE) were sorted to determine the scenarios that yielded the greatest and smallest differences from normal hearing. After sorting, each hearing loss type was given a rank, with 1 corresponding to the smallest MSE and 7 to the greatest. There appears to be a trade-off between the ability of the upper tone and the lower tone to match normal hearing performance. Also of interest is that the best and worst cases seem to be consistent across hearing loss types and also across different hearing aid amplification formulas. The MSE error for each simulation case is affected by several factors. For the lower tone MSE the lower tone frequency, lower tone SPL and average HL have a significant effect ($p < 0.0001$). For the upper tone MSE the lower tone frequency, lower tone SPL, average hearing loss and the addition of an ADC or ADC and Noise Reduction all have significant effect ($p=0.0001, p < 0.0001, p < 0.0001, p < 0.0001$). From Fig. 6 the addition of the simple noise reduction filter reduces the MSE.

Data	HA only	HA and ADC	HA with ADC and NR
MSE, DSL	0.85	0.84	0.39
MSE, NALR	0.93	0.93	0.62
Ranking, DSL	0.93	0.70	0.36
Ranking,NALR	0.90	0.91	0.63

Table 1: R^2 values for each linear fit.

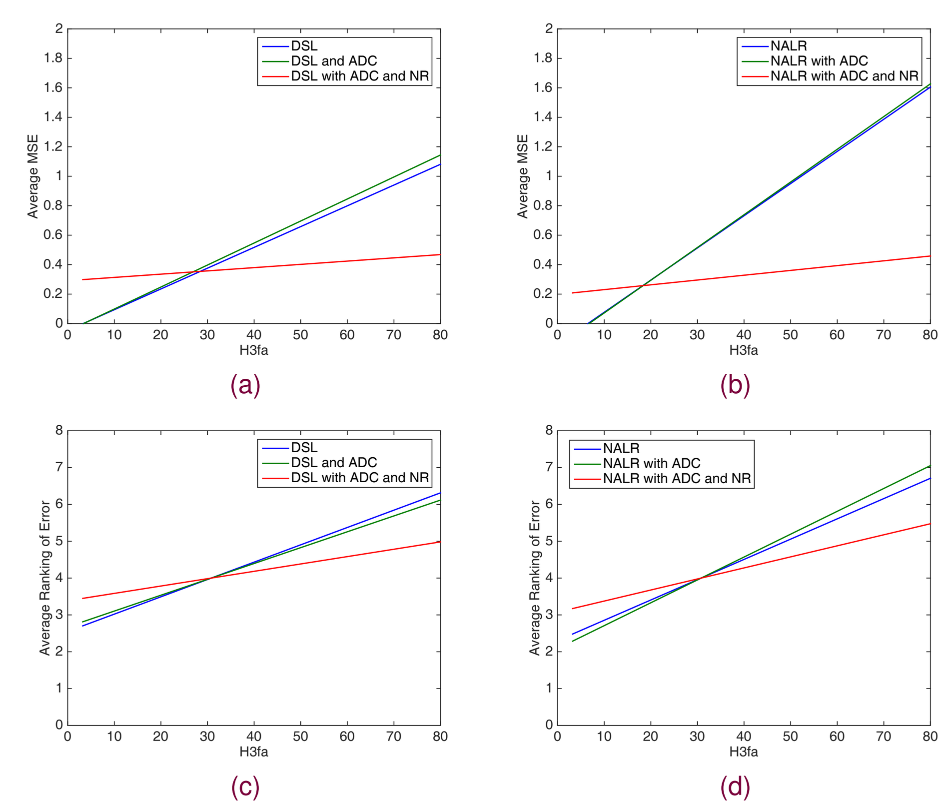

Figure 6: MSE (top panels) and average ranking (bottom panels) vs average hearing loss (H3fa) for (a,c) DSL and (b,d) NALR amplification.

From Fig. 3 the noise reduction algorithm tends to cancel out the high frequency tone, particularly for the higher harmonics. For normal hearing and milder amounts of hearing loss this will worsen the pitch salience for that tone, increasing the overall error. For greater degrees of hearing loss the cancelled high tone would improve the salience of the low tone, reducing the overall error.

LIVE MUSIC RECORDINGS: METHODS

Live music recordings were done with three members of the McMaster Marching Band playing flute, tenor saxophone and clarinet in the LIVELab at McMaster. The piece played was an arrangement of 2001 Fanfare created for the Marching Band.

Figure 7: Instrumental parts for 2001 fanfare.

- The LIVELab is a unique space that is naturally an extremely quiet room (<10 dB of background noise) with a Meyer Sound Active Acoustic System that can be used to simulate a range of acoustic environments (`http://livelab.mcmaster.ca`).
- Recordings were done with KEMAR sitting in a central seat in the LIVELab that was found to have minimal difference in frequency content and reverberation time across the two ears.
- The musicians played from centre stage.
- Recordings were done with two different reverberation times with and without hearing aids.
- The hearing aids were set for three of the hearing loss audiograms used in the simulations; an 80dB flat hearing loss, moderate-severe noise induced hearing loss and no hearing loss.
- The recordings were done using Unitron Moxi Kiss hearing aids on KEMAR.
- The recordings were compared to wav files of the 2001 fanfare piece generated by the music editing software MuseScore and also piano versions of each part.

LIVE MUSIC RECORDINGS: RESULTS

Some sample pitch salience results are shown in Fig. 8 and Fig.9 along with the frequency of the tones being played by both instruments at each time period.

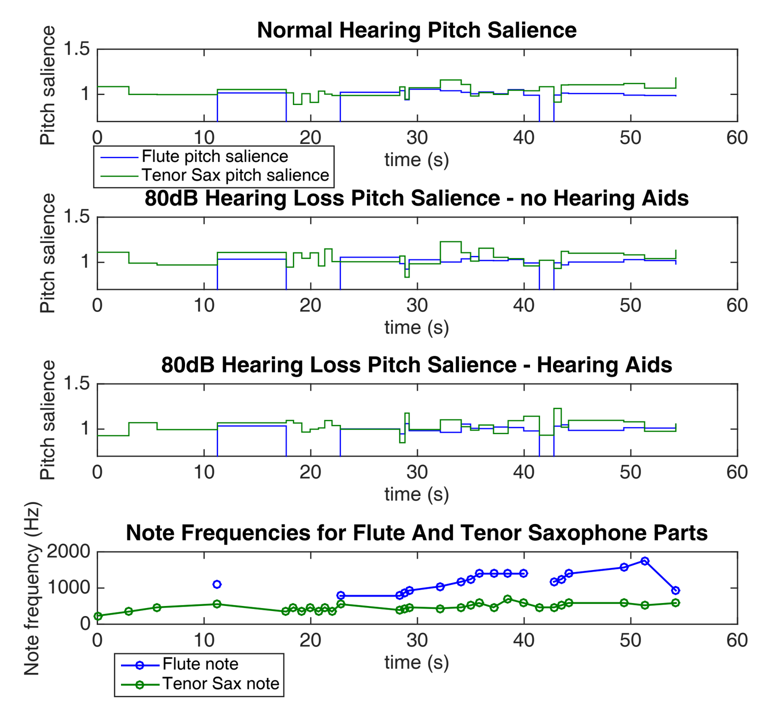

Figure 8: Examples of pitch salience results for the KEMAR recordings with and without hearing aids.

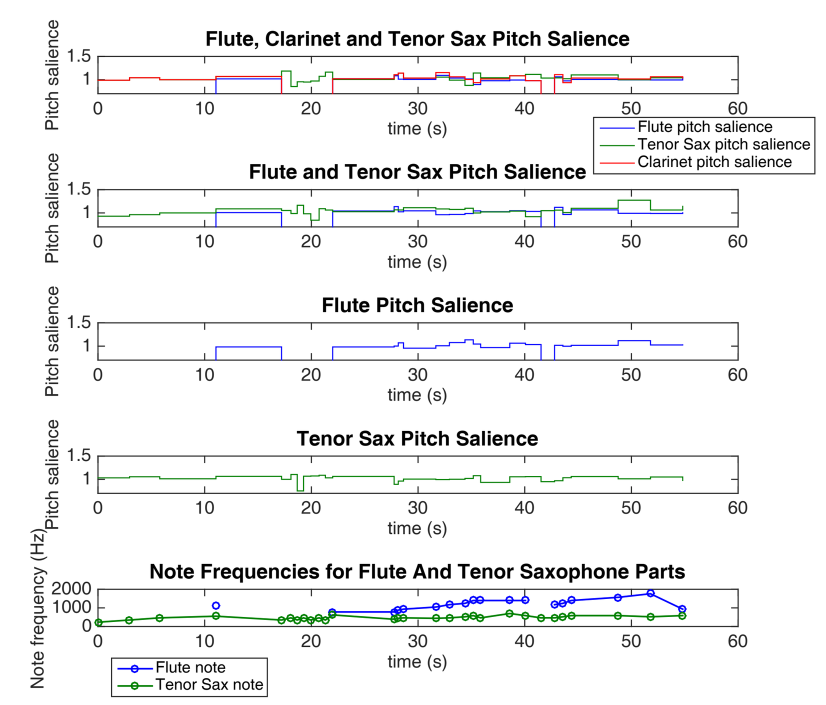

Figure 9: Examples of pitch salience results for the KEMAR recordings with different instrument combinations.

Figure 10a shows the MSEs when comparing the neural pitch salience profiles of the recordings to the wav files of the instrument parts generated by MuseScore. Figure 10b gives the MSEs when the recordings are compared to simulated piano tones.

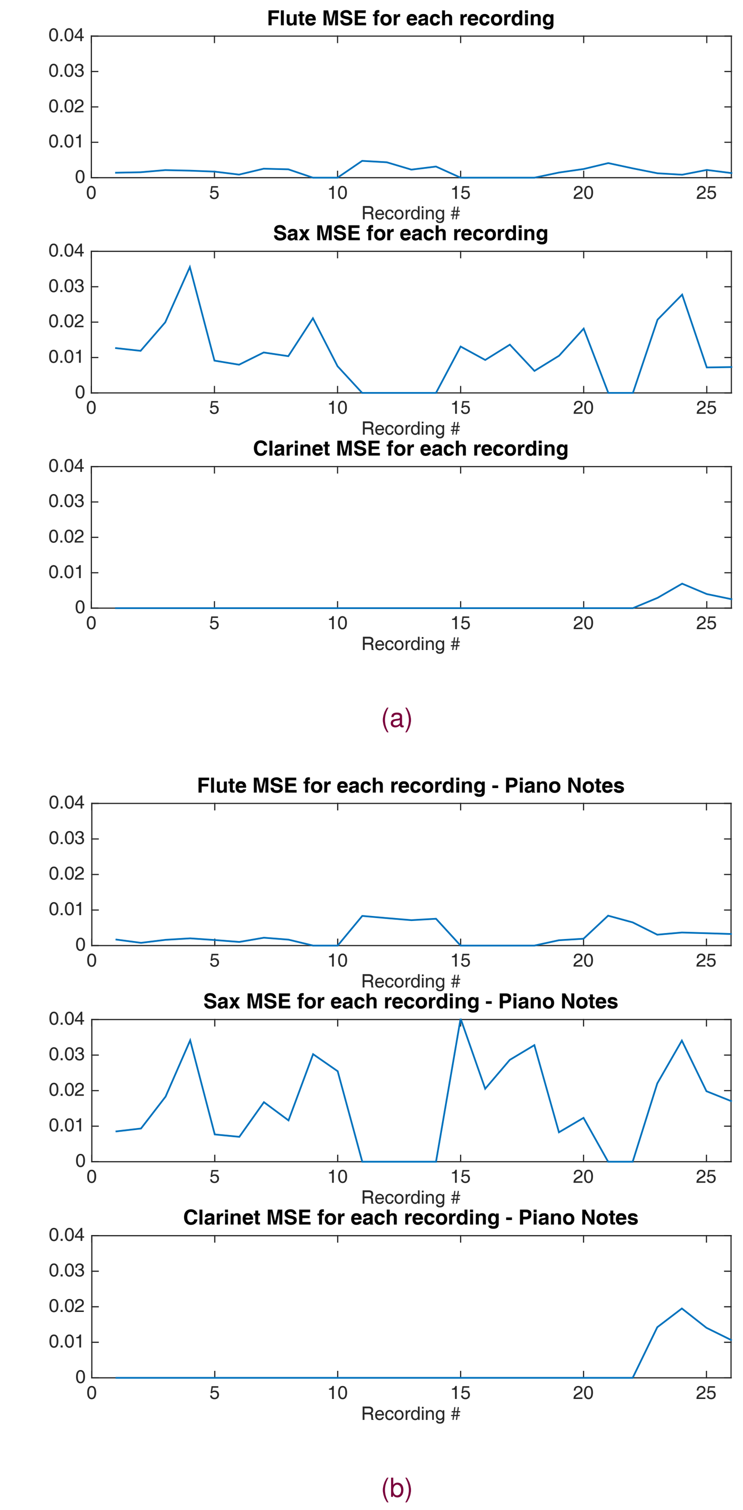

Figure 10: Comparison of pitch salience for normal hearing from recordings to input from (a) the idealized wav file or (b) simulated piano tones.

CONCLUSIONS

- For more severe hearing loss the pitch salience profile is further from normal, even after hearing aid amplification.
- The noise reduction filter used here improves the pitch salience of the lower tone for more severe hearing loss but reduces the salience of the upper tone.
- For the live music recordings, the flute performance gave pitch saliences that were more similar to the idealized wav file and piano tone simulation than did the clarinet or tenor saxophone performances.

Acknowledgements

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