THE PROBLEM WITH FREQUENCY TRANSPOSITION AND MUSIC:

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Introduction:

Frequency transposition, frequency shifting, and frequency compression are all terms that refer to algorithms that lower the frequency above a certain start point using either a linear or a non-linear processing. Many manufacturers have their own terminology for their algorithm and in some cases, manufacturer's software will include in as a default setting for their first-fit algorithms. In this article I will be using the phrase "frequency transposition" generically, to refer to shifting a range of frequencies to a lower frequency range.

Many people that have a hearing loss have frequency regions that are significantly damaged, whereas other frequency regions are healthier. For example, a person with a hearing loss may perceive a note on the right hand side of the piano keyboard to be flat or distorted, and in some cases, no matter what is done to the setting on the hearing aids, these notes will not sound good. This have been referred to as a "cochlear dead region", and as this overly dramatic sounding name suggests, it is best to avoid this frequency region (Baer et al., 2002; Moore, 2004; Moore, 2010). A short-cut to quickly assessing cochlear dead regions can be found in Chasin (2019).

Music is not speech:

For speech, frequency transposition works very well, but music is not speech. Music is made up exclusively of notes and their harmonics. Harmonics need to occur at exact frequencies, not sharp and not flat. Using frequency transposition will alter the frequency of a range of harmonics and this altered harmonic structure would be, at best flat, and at worst highly dissonant. In contrast for speech, those sounds that are frequency compressed are the higher frequency 's' and 'sh' sounds; sounds that are broad band noise or sibilant in nature, and not at "exact" frequencies. It doesn't matter whether a sibilant sound may have a broad band of frication centered at 4500 Hz or 4200 Hz.

The following three examples can illustrate this potential difficulty: A flute and an oboe, or for that matter a flute and a violin, or a flute and a tuba, have identical harmonics at exactly the same set of frequencies. For those of you who like science, each of these musical instruments are called "half wavelength resonators", and unfortunately they are still called "half wavelength resonators" even if you don't like science. This means that when a flute (or a violin, or a tuba, or a wide range of other musical instruments) plays A (440 Hz), the second space on the treble clef, there are a range of harmonics at multiples of 440 Hz; namely 880 Hz, 1320 Hz, 1760 Hz, and so on. In order to be on key (and not sharp or flat), the harmonics need to be exactly at 880 Hz, 1320 Hz, 1760 Hz and not flat at 850 Hz, 1300 Hz, and 1700 Hz.

Even reducing a higher frequency harmonic by one half of one semi-tone, frequency transposition can completely destroy the music and only the word "dissonance" would describe it. Clinically it is better to just reduce the amount of hearing aid amplification in this frequency region (i.e., the third audio file), rather than try to change its pitch.

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The first audio file is an “A-B-A” comparison. This means that the first part of the audio file (A) is a violin playing A (440 Hz), the second part (B) is the same violin sound but with a slight application of frequency transposition where the higher frequency harmonics (above 1500 Hz) are only decreased by one half of one semi-tone, and the third part (A) is the original unaltered violin again, for comparison. Clinically frequency transposition is commonly used to create changes far in excess of only one half of one semi-tone.

The second audio file is again an “A-B-A” comparison but this time actual full orchestral music is used and not just an individual note. Again, the same frequency transposition is applied only above 1500 Hz and only one half of one semi-tone. Note the dissonance in the early part of the B section as the music goes up a scale. And the final “A” part is the same as the original unaltered music.

The following spectrum shows the subtle difference that was created by just lowering the harmonics above 1500 Hz by one half of one semi-tone. The blue colored lines are for the unaltered original sound, and the white colored lines are for the slightly frequency compressed altered sound. This can be thought of as a piano keyboard with the left hand side being the bass notes and the right hand side being the treble notes/harmonics.

The third audio file is again an “A-B-A” comparison like the first audio file except that the sound above 1500 Hz has been gradually reduced in intensity by rolling off everything by 6 dB/octave, instead of applying frequency transposition. This is not perfect but this gain reduction is a better clinical approach whenever one wants to avoid dissonance associated with a cochlear dear region for music.

The one octave counter-example- an island of refuge:

Are there specific frequency transpositions that would be acceptable? As it turns out, more may not necessarily be such a bad thing. Just because one half of a semi-tone or a full semi-tone may sound bad, doesn’t necessarily mean that 2 or 8 semi-tones would be worse. There may be “islands” where the frequency transposition doesn’t sound too bad.

It is true that a transposed harmonic (or range of harmonics) can co-incidentally line up with a different pre-transposition harmonic, thereby not creating dissonance, and other than a slight increase in overall harmonic intensity, this should sound good. And there can be other transposed harmonics that can create “new” harmonies such as a major third or perfect fifth, which will also not cause dissonance in the music. It the latter case, it would still sound great, but not be as originally orchestrated… something that my music teacher may call “funky”. For the non-music readers, the word “funky” in jazz means “different, but OK”. In classical music, “funky” can also mean “go home and practice more!” I suspect that the creation of some unexpected harmonics may be more acceptable for classical music than the more complex harmonies and counterpoint associated with jazz music.

In the specific case of a one octave frequency transposition, the first harmonic in the transposed region (e.g. only above 1500 Hz) would line up perfectly with the pre-exposed harmonic just below it in frequency, and this would be the case of all odd number multiples above that. For the even numbered harmonics above the first harmonic to be transposed, the result would be one that is a perfect fifth, which would not sound dissonant. The even numbered harmonics would all be at the geometric mean of the octave below it, like an A being changed to an E. The notes A and E can sound quite nice together, but the orchestrator did not include a perfect fifth in the original music.

The following audio file shows a violin transposed exactly one octave above 1500 Hz, in an A-B-A comparison where the "A" portion is the untransposed note and the "B" portion is the transposed note. The untransposed and transposed spectra are also shown with the blue color for the unaltered violin spectrum playing A (440 Hz) and the white color for the spectrum that has been frequency transposed by exactly one octave. Note the creation of "additional" harmonics at the perfect fifth. That is, an E (1319 Hz)- actually an octave and a perfect fifth higher than A (440 Hz)- is created where none had existed before, but the musical notes A and E sound quite nice together.

However, this is a case where the violin was used as an example. The violin, like the saxophone, guitar, piano, oboe, and a range of other instruments are one half wavelength resonators with integer multiples of their harmonics. But this one octave transposition should also be able to be useful for one quarter wavelength resonator instruments such as the clarinet, trumpet, and French horn where the fundamental note would have "odd" numbered multiples. This is why there is a special key on the clarinet called a "register" key rather than the "octave" key that is found on the saxophone. A register key increases the frequency by 3 times the similar fingering in the lower register; an odd numbered multiple (or an octave and one half).

With a clarinet, a one octave transposition would also create additional harmonics that were not in the initial orchestration, but in this case they would be major thirds- again it still sounds great but not exactly what the music composer had in mind.

The following audio file shows a clarinet transposed exactly one octave above 1500 Hz, in an A-B-A comparison where the "A" portion is the untransposed note and the "B" portion is the transposed note. The untransposed and transposed spectra are shown. Similar to the previous case of the violin, the blue color is for the unaltered clarinet spectrum playing A (440 Hz) and the white color is for the spectrum that has been frequency transposed by exactly one octave. Note the creation of "additional" harmonics at the major third. That is, a C is created where none had existed before, but the musical notes A and C also sound quite nice together.

My clinical "gut" feeling is that all forms of frequency transposition may be useful for speech but not for music, however manufacturers may want to consider creating a "one octave frequency transposition" button in the software that may be "tried" as part of a music first-fit program.

Acknowledgment:

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References:

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