Preference for compression speed in hearing aids for speech and music and its relationship to sensitivity to temporal fine structure

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Multi-channel amplitude compression is widely used in hearing aids. The preferred compression speed varies across individuals. Moore (2008) suggested that reduced sensitivity to temporal fine structure (TFS) may be associated with preference for slow compression. This idea was tested using a simulated hearing aid. We also assessed whether preferences for compression speed differ for speech and music. Eighteen hearing-impaired subjects were tested, and the stimulated hearing aid was fitted individually using the CAM2 method. On each trial a given segment of speech or music was presented twice, once processed with fast compression and once with slow compression, in random order. The subject indicated which segment was preferred and by how much. On average, slow compression was preferred over fast compression, more so for music, but there were distinct individual differences, which were highly correlated for speech and music. Sensitivity to TFS was assessed using the difference limen for frequency at 2 kHz and by two measures of sensitivity to interaural phase at low frequencies. The results for the DLFs, but not the measures of sensitivity to interaural phase, provided some support for the suggestion that preference for compression speed is affected by sensitivity to TFS.

INTRODUCTION

People with cochlear hearing loss usually experience loudness recruitment, and the associated reduced dynamic range (Fowler, 1936; Moore, 2007). Most modern hearing aids incorporate some form of amplitude compression or automatic gain control (AGC) to deal with this. In principle, AGC can make low-level sounds audible while preventing high-level sounds from becoming uncomfortably loud. However, controversy continues about the "best" way to implement AGC, and in particular whether it should be fast acting or slow acting (Gatehouse *et al.*, 2006a; 2006b). In this study we assessed the preferences of 18 hearing-impaired subjects for fast relative to slow compression, using a simulated hearing aid. The study was

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intended to answer two questions: (1) Are preferences for slow versus fast compression consistent for speech and music stimuli? For example, if an individual prefers slow compression for speech, will they also prefer slow compression for music? (2) Are preferences for compression speed related to sensitivity to temporal fine structure (TFS), as hypothesized by Moore (2008)?

Moore (2008) suggested that individual differences in "best" compression speed might be related to sensitivity to the temporal fine structure (TFS) of the waveforms evoked by sounds on the basilar membrane. Hearing-impaired subjects perform more poorly than normal-hearing subjects on tasks that are thought to rely on sensitivity to TFS, for example discrimination of harmonic and frequency-shifted tones (Hopkins and Moore, 2007; 2010b; Moore, 2014), interaural phase discrimination (Lacher-Fougère and Demany, 2005; Hopkins and Moore, 2011), and detection of low-rate frequency modulation (Moore and Skrodzka, 2002; Strelcyk and Dau, 2009). Hopkins *et al.* (2008) and Hopkins and Moore (2010b) reported high variability in the ability of hearing-impaired subjects to use TFS information, some being completely insensitive to TFS information and others having a similar ability to use TFS as people with normal hearing. Moore (2008) suggested that hearing aid users with good TFS sensitivity may benefit more from fast than from slow compression, as TFS information may be important for listening in the dips of a fluctuating background (Moore and Glasberg, 1987), and fast compression increases the audibility of signals in the dips (Moore *et al.*, 1999). However, people with poor TFS sensitivity may rely mainly on temporal envelope information in different frequency channels, and for them it may be important to avoid the temporal envelope distortion that can be introduced by fast compression (Stone and Moore, 1992; 2004; Stone *et al.*, 2009).

The present study used hearing-impaired subjects to assess whether relative preferences for fast versus slow compression were related to sensitivity to TFS. A previous study did not support that hypothesis, but that study used simulated hearing loss and simulated loss of sensitivity to TFS (Hopkins *et al.*, 2012). Since hearing aids are often used for listening to music as well as for listening to speech (Leek *et al.*, 2008; Kochkin, 2010; Madsen and Moore, 2014), we used both speech stimuli and music stimuli. The results were intended to determine whether individual preferences for compression speeds were consistent across speech and music stimuli. All subjects were assessed for their sensitivity to TFS, using three tasks.

METHOD

Subjects

Eighteen subjects (11 male) with moderate-to-severe sensorineural hearing loss were paid to participate. Their ages ranged from 56 to 87 years. Sixteen were current users of multi-channel compression hearing aids and two did not use hearing aids. Audiometric thresholds were measured for all audiometric frequencies from 0.25 to 10 kHz. Only the better ear of each subject was tested using the paired-comparison procedure. The hearing loss in the test ear ranged from 8 to 60 dB at 500 Hz, 6 to 64 dB at 1000 Hz, 26 to 70 dB at 2 kHz, 48 to 74 dB at 4000 Hz, and 54 dB to >100 dB at 8000 Hz.

Simulated hearing aid

The simulated hearing aid was the same as described by Moore *et al*. (2010a) and Moore and Sek (2013). Briefly, the aid included a digital filter for overall shaping of the frequency response prior to splitting the signal into five channels, with independent compression in each channel. The insertion gains for a 65-dB speech-shaped noise and the compression ratios (CRs) for the five channels were set according to the CAM2 prescription method (Moore *et al.*, 2010b), modified slightly as described in Moore and Sek (2013). The compression thresholds were set to 49, 41, 40, 34, and 28 dB SPL for channels 1-5, respectively.

To simulate fast compression, the attack/release times (ANSI, 2003) were set to 10/100 ms for all channels. To simulate slow compression, the attack/release times were set to 50/3000 ms for all channels. The CR was limited to 3 when fast compression was used, since there is evidence that with fast compression high CRs can lead to reduced speech intelligibility (Verschuure *et al.*, 1996). The CR was allowed to have any value up to 10 when slow compression was used.

Stimuli

The speech stimuli were digitally recorded segments of running speech (connected discourse) obtained from one male and one female talker of British English. One 4.8-s segment of speech was selected for each talker. The music signals were: a 7.3-s segment of a jazz trio (piano, bass, and drums); a 5.6-s segment of an orchestra (including brass instruments and cymbals) performing Bizet’s Carmen; a 3.5-s segment of a xylophone playing the “Sabre Dance” by Khachaturian (anechoic recording); and an 8.4-s segment of a counter-tenor accompanied by guitar and recorder. For all signals, the diffuse-field equivalent level at the input to the simulated hearing aid was 50, 65, or 80 dB SPL.

Paired-comparison procedure

The procedure was similar to that described by Moore and Sek (2013). On each trial the same segment of sound was presented twice in succession, once processed with fast compression and once with slow. The possible orders were used equally often and the order was randomized across trials. Within a given pair of sounds, the only difference between the sounds was in the compression speed; the input level was always the same. The subject was asked to indicate which of the two was preferred and by how much, using a slider on the screen. The continuum was labelled “1 much better”, “1 moderately better”, “1 slightly better”, “equal”, “2 slightly better”, “2 moderately better”, and “2 much better”.

For a given trial, if fast compression (FAST) was preferred the slider position was coded as a negative number and if slow compression (SLOW) was preferred the slider position was coded as a positive number. The overall score for each compression speed and stimulus type (e.g., classical music) was obtained by averaging all of the sub-scores obtained for that speed and stimulus type. A score of –3 would indicate a very strong and perfectly consistent preference for FAST whereas a score of +3 would indicate a very strong and perfectly consistent preference for SLOW. A score of 0 would indicate no preference.

Measurement of sensitivity to TFS

To estimate sensitivity to TFS at medium frequencies, we measured the difference limen for frequency, DLF, using a method similar to that described by Moore and Ernst (2012). It is widely believed that the DLF is based on a temporal rather than a place mechanism for low and medium frequencies (Moore, 2014). A two-interval, two-alternative forced-choice task was used. One interval contained four successive 2-kHz tones. The other interval contained four successive tones whose frequency alternated between 2 kHz and 2 kHz + Δf. The subject had to choose the interval in which they heard a fluctuation in pitch. The value of Δf was varied adaptively to determine the DLF corresponding to 70.7% correct.

To estimate sensitivity to TFS at low frequencies, we used the TFS-LF test (Hopkins and Moore, 2010a; Sek and Moore, 2012), which estimates the threshold for discriminating an interaural phase (IP) of 0° from an IP of $\Delta\varphi$. For this test, the tones had a frequency of 500 Hz and the starting value of $\Delta\varphi$ was 180°. In addition, we used a new test, in which the IP difference was fixed at 180° and the frequency of the test tone was adaptively varied to determine the highest frequency at which the task could be performed (Füllgrabe *et al.*, 2015). The starting frequency was 500 Hz. The time pattern of the stimuli was the same as for the TFS-LF test. All subjects could perform the task when the frequency was made sufficiently low. We refer to the modified task as the TFS-AF task, where AF stands for adaptive frequency.

For all three tests, each tone lasted 400 ms, including 20-ms raised-cosine ramps. The silent gap between the tones within an interval was 100 ms. The gap between intervals was 400 ms. The stimuli were presented at 30 dB sensation level (SL).

RESULTS

Compression speed preferences for speech

The preference scores were averaged across the three levels. The average preference scores for the male talker and the female talker were highly correlated (r = 0.93, p < 0.001). This indicates that the subjects were consistent in their ratings across talkers. In what follows, only the mean ratings across talkers are considered. Fig. 1 shows individual and mean preferences for speech. On average, SLOW was preferred over FAST, but only by 0.46 scale units. There were distinct individual differences. Eight subjects showed a preference for SLOW of 0.5 scale units or more, while four subjects showed a preference for FAST of 0.5 scale units or more.

Compression speed preferences for music

The preference scores were averaged across the three levels. The scores were reasonably consistent across music types except the solo percussion instrument, for which the scores were not significantly correlated with scores for the other music types. Hence, we consider only the mean scores across the three other music types. Fig. 2 shows individual and mean preferences for music. On average, SLOW was preferred over FAST, by 0.57 scale units. Seven subjects showed a preference for SLOW of 0.6 scale units or more, seven showed no clear preference (ratings within the range –0.014 to +0.18), and no subject showed a clear preference for FAST.

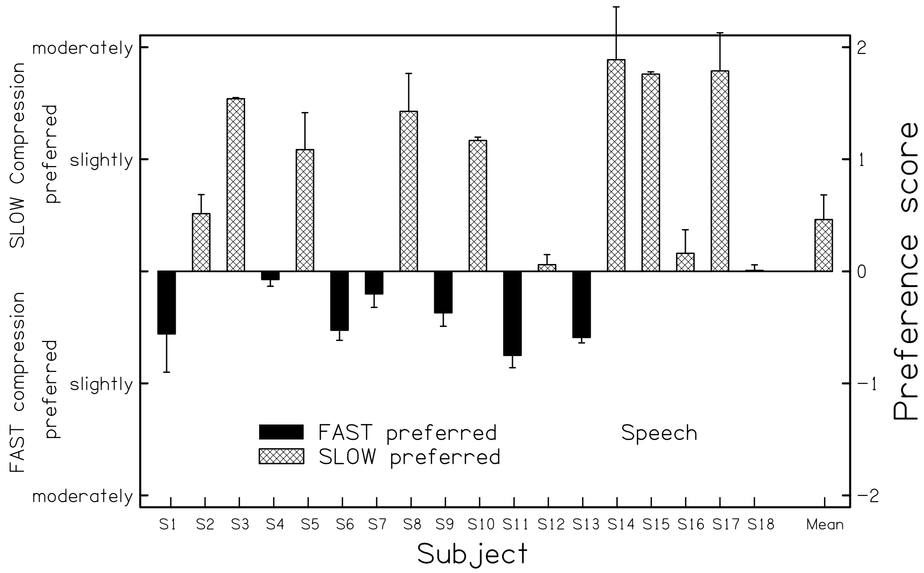

Fig. 1: Mean preference scores for speech for each subject. Error bars show ±1 SD. The bar at the right shows the mean.

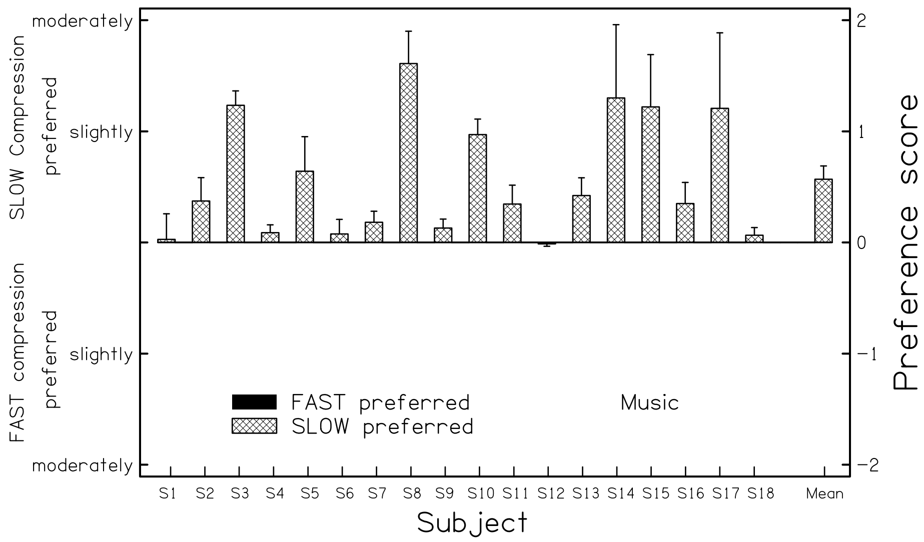

Fig. 2: As Fig. 1, but for music (percussion excluded).

Similarity of preferences for speech and music

Although the preference for SLOW relative to FAST was slightly greater for the music than for the speech stimuli, the pattern of preferences across subjects was highly correlated for the two stimulus types ($r = 0.89$, $p < 0.01$), as can be seen by comparing Figs. 1 and 2.

Relationship of preferences to sensitivity to TFS

Since we were testing the hypothesis that the relative preference for slow compression would increase with decreasing sensitivity to TFS, one-tailed tests were used to assess the significance of correlations. The DLFs for the test ears were weakly correlated with preference scores for music: $r = 0.4$, $p < 0.05$. Large DLFs, indicating poor sensitivity to TFS, were associated with greater preference for SLOW. However, the correlation of DLFs with preferences for speech failed to reach significance: $r = 0.31$, $p > 0.05$.

Six subjects were not able to complete the TFS-LF task, because the adaptive procedure called for a value of $\Delta\varphi$ greater than 180°. For the 12 subjects who were able to complete both the TFS-LF and the TFS-AF tasks, there was a strong negative correlation between the two ($r = -0.93$, $p < 0.01$), indicating good consistency across the two tests; good interaural phase sensitivity was associated with a low threshold in degrees on the TFS-LF test and a high threshold in hertz on the TFS-AF test. Scores on the TFS-AF task, which could be completed by all subjects, were not significantly correlated with compression-speed preferences for either speech or music (both $r = -0.1$, $p > 0.05$).

DISCUSSION AND CONCLUSIONS

Consistent with the research reviewed in the introduction, there were distinct individual differences in preferences for SLOW relative to FAST. On average, the relative preference for SLOW was slightly greater for music than for speech, but the pattern of preferences across subjects was similar for speech and music. The use of slow compression seems to be a “safe” option for music listening, since several subjects showed relatively clear preferences for SLOW, while none showed a clear preference for FAST. However, for speech four subjects showed a clear preference for FAST.

The preferences were not related to the measures of sensitivity to interaural phase at low frequencies. A possible reason is that some of the subjects had near-normal hearing at low frequencies, and for them little compression was applied at low frequencies. There was a weak correlation between the DLFs at 2 kHz and preferences for music but not preferences for speech. Thus, while sensitivity to TFS may have a weak influence on preferences for compression speed, other factors, such as cognitive ability (Gatehouse *et al.*, 2006a; 2006b; Lunner and Sundewall-Thoren, 2007), appear to have a more important influence.

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