EFFECTS OF HEADPHONE TRANSFER FUNCTION SCATTERING ON SOUND PERCEPTION

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INTRODUCTION

• HEADPHONE TRANSFERT FUNCTION

• Headphone extensively used for binaural reproduction, psychoacoustics experiments, sound engineer works, domestic use…

• Attention is paid to the transducer quality but not to the coupling between the headphone and the listener's ears.

• HPTF: both the headphone response and the coupling to a listener's ear.

• HPTFs may exhibit similar spectral features as HRTFs [Kulkarni and Colburn 2000; McAnally and Martin 2002].

• HPTFs can be inverted to compensate for the headphone influence and recreate the exact signals at the listener's ears.

• Significant inter-individual variability from 4 to 10 kHz → Non-individualized equalization can lead to errors in localization tasks [Pralong and Carlile 1996].

• MEASURED EFFECT OF HEADPHONE POSITION

• When HPTFs are inverted (rare), their measures are averaged from repeated measurements: scattering caused by differences in the headphone position over the listeners' ears is not taken into account.

• Nevertheless slight modifications in the headphone placement can cause large spectral differences: standard deviation can reach up to 9 dB above 10 kHz [Toole 1984, Wightman and Kistler 1989, Pralong and Carlile 1996, Kulkarni and Colburn 2000].

• HEADPHONE POSITION AND LOCALIZATION

• Headphone placement does not affect localization accuracy [Martin et al. 2001].

• The variability of HRTFs passed through a cochlear filter model is higher than that of filtered HPTFs → the spectral information used by listeners to localize sound is unlikely to be masked by the variability of the HPTF magnitude [McAnally and Martin 2002].

• PERCEIVED EFFECT OF HEADPHONE POSITION

• Audiometric testing: differences up to 15 dB have been observed in hearing thresholds because of bad headphone positioning [Green 1994].

• Peaks and dips similar to those observed on HPTFs are audible [Bücklein 1962].

• The aim of this study is to evaluate whether realistic changes in the headphone placement lead to noticeable differences :
- Direct test cannot be blind : stimuli have to be recorded beforehand.
- Monophonic sequences have been recorded on an artificial head for 8 placements of 2 headphones.
- Recordings are played back over a fixed headphone.
- Listener's task: differentiate recordings from different headphone placements.

RECORDINGS

• 3 short excerpts:
- Pink noise (3.5 s).
- Ben Harper (5 s) (drums, acoustic guitar, male and choir voices).
- Leonard Bernstein (4 s) (symphonic orchestra).

• Monophonic sequences: only the left channel for the two musical excerpts.

• 2 open headphones:
- A-Sennheiser HD497 (supra-aural).
- B-Sony MDR CD580 (circum-aural).

• Neumann KU 100 dummy head:
- Omnidirectional microphones.
- Blocked ear canal [Møller et al. 1995].

• Excerpts recorded in 8 different positions per headphone model.

Recording of sequences played on headphones in the ears of the KU 100 dummy head.

SIGNAL PROCESSING

• NORMALIZATION OF RECORDING LEVEL

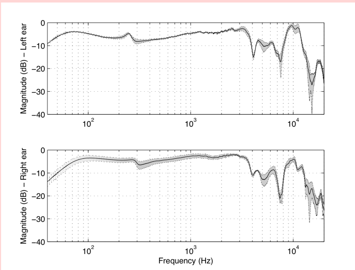
• Normalization of the average levels per headphone: compensation for the different headphone sensitivities.

• COMPENSATION FOR THE PERCEPTUAL TEST HEADPHONE

• Sony MDR CD2000.

• Inverse filtering (from the average of 8 measurements on the dummy head).

• Non perfect filtering, but identical for all the recording positions [Møller et al. 1995].



Transfer function (mean and standard deviation) of the Sony MDR CD2000 headphone for the left (up) and right ear (down).

TEST PROTOCOL

• 3I-3AFC response paradigm (3-Interval 3-Alternative Forced Choice):
- Successive presentation of 3 intervals.
- 1 interval is different from the 2 others: oddball stimulus.
- The listener has to indicate the oddball stimulus.

• 8 positions, 2 headphones, 3 excerpts.

• 28 trials are needed to compare the 8 stimuli (from 8 positions) for 1 given excerpt and 1 given headphone.

• Test lasted 45 minutes (including pre-test and break).

• 10 expert listeners, 10 naïve listeners.

• Listeners were told to place the test headphone comfortably and to not modify its position hence the test had started.

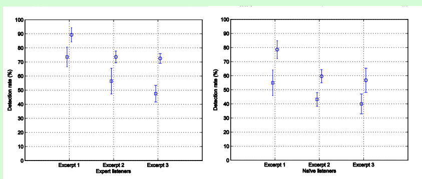
• Restitution level fixed for all the listeners (realistic level for music, 75dB SPL for white noise).

RESULTS (1)

• AUDIBILITY OF THE POSITIONING VARIABILITY

• Chance with a 3I-3AFC paradigm : 33.33%.

• Detection rates always significantly higher than 33.33% (t-test: p<0.003 in the least significant case), except for the case "naïve listener, headphone A, excerpt 3" (40%, p=0.1).



Mean detection rates for the headphones A (○) and B (○), the 3 excerpts, and the two listener groups within their 95% confidence interval

RESULTS (2)

• HEADPHONE EFFECT

• ANOVA: significant headphone effect (F(1,108)=98.19; p <0.0001).

• Detection of the oddball stimulus more difficult for the recordings made using the headphone A (Sennheiser HD497) than for the headphone B (Sony MDR CD580).

• LISTENER'S BACKGROUND EFFECT

• ANOVA: significant effect of listener's background (F(1,108)=47.39; p<0.0001).

• Detection of the oddball stimulus more difficult for the naïve listeners than for the expert ones.

• EXCERPT EFFECT

• ANOVA: significant excerpt effect (F(1,108)=39.75; p<0.0001).

• Fisher LSD: detection of the oddball stimulus easier with the pink noise than with the two musical excerpts (p<0.0001). Musical excerpts equivalent (p=0.09).

CONCLUSION

• POSITIONING VARIABILITY: AUDIBLE !

• Headphone positioning variability produces audible differences in most cases (except the condition "naïve listeners, Leonard Bernstein excerpt").

• As it could be thought from past studies, the action of placing and replacing a headphone over a listener's head causes significant modifications to the signal (objectively and perceptually). So the frequency smoothing applied by the inner ear doesn't totally filter out the differences induced by successive replacements.

• Headphone positioning variability lower if listeners place themselves on their own head [Møller et al. 1995]. Nevertheless, the obvious audibility of the differences caused by successive positions over a dummy head, could get to think that the differences would be audible with real heads.

• DIFFERENCES MORE EASILY PERCEIVED USING PINK NOISE THAN MUSICAL EXCERPTS.

• Pink noise: steady-state signal, facilitates the memorization effort, large spectral content ensuring that the spectral modifications caused by a specific position, with possible high-Q peaks and dips, would be highlighted.

• [Bücklein 1981] observed that the detection of spectral peaks and dips was more accurate using white noise than music. He assumed that the audibility of the resonances increased with the spectral content.

• NEED TO COMPENSATE POSITIONING VARIABILITY ?

→ Not sure !

• In binaural synthesis, it has been shown that the peaks characterizing the HPTFs were so high that the HPTF variability was negligible [McAnally and Martin 2002].

• For sound recording industry, it can be thought that the microphones, equalizations or processing used by sound engineers modify the signal in a more significant manner than the differences in headphone placement.

• Hard to compensate: a real-time equalization would require an in-ear microphone… and only a probe tube would not close the ear canal… but would therefore be of poor reliability…

… but the headphone positioning variability is perceptible and should be taken into account…

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