Part IVa: Effect of *Cavum Conchae* Blockage on Human Head-Related Transfer Functions

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Abstract

The second part of the current triplet investigation concerning various quality issues in *head-related transfer functions (HRTFs)* focuses on specific measurement problems. The effects of the earplugs, i.e., compressible *polymer foam and moldable silicone*, are reviewed from both practical and empirical standpoints. The silicone putty is likely to cause better (more repeatable) HRTF characteristics, and it is studied further. The amount of putty (while sufficient enough) *changes the overall gain in HRTFs*, independent of direction, but depending on the particular ear and frequency, typically approx. *±5..15 dB (≥7 kHz)*. The *cavum conchae eigenfrequencies* are not changed due to adjusting the amount of the silicone in the *meatus.*

1. Background

Still a decade ago the standard method was to use bulky probe microphones for HRTF measurements, which were potentially hazardous to the subject and suffered from a poor signal-to-noise ratio (SNR) [1]. Different approaches were used to set the probe at the desired position; see, e.g., [1, 2]. Nowadays, the majority of HRTF measurements are performed at the entrance of the blocked ear canal (*meatus*), which is considered to render all significant auditory localization cues; see, e.g., [2]. This is also promoted by modern electronics, as miniature electrets are relatively cheap (< 100 USD) and have much better SNR than the probe microphones. Furthermore, the blockage removes – or at least should remove – the problematic ear canal resonance effect.

2. Introduction

This study is the parallel half of [3] of the current triplet study [3-5], whose first part [3] should be first familiar to the reader, because not only the *methodology* but also partly the *measurement data* is joined.

2.1. Quality of applied HRTF data

The high quality of the HRTF data obtained with the measurement system and test subject + microphone position procedure is discussed in [3], and analyzed more in detail in [6-8].

2.2. Means of analysis

Point-to-point dB-magnitude difference plots utilized demonstrate clearly the variation caused by the minute variations between the measurement sessions, whose raw responses are *0.1 octave smoothed*, *system compensated* and level adjusted (mean <1 kHz) in order to remove the gain offsets between different treatments. A large set of sound reveals the results for the complete three-dimensional space.

3. Effect of plug type

Different blockage materials are used for HRTF measurements, e.g., EAR and rings (seals) and silicone putty. This chapter considers their practical problems and considers how they affect the measured HRTFs.

3.1. Use of different ear plugs

The author started his experimental HRTF research (01-02/1997) applying the Classic EAR plugs, which are made of soft energy absorbing polymer foam [9]. In order to fit the capsule to the surface, a small cavity (ø=l≈4 mm) was burned with a soldering iron into the center of the EAR [10]. Even so, already after a couple of measurements the difficulties of fitting reliably the microphone capsule/cord on top of the plug were noticed:

1) the foam itself is not sticky and *it does not "glue" the microphone capsule* to the correct position [using extra adhesive is should be avoided due to health risk for both the subject and the capsule],
2) the porous foam may uncork after a while, if it is not fitted *perfectly* into the auditory canal and if the microphone cables are not taped well for strain relief,
3) for many persons the yellow EAR is *too big*; the *smaller pink EAR plug does not offer sufficient volume for sealing* peripherally the capsule (the microphone is too big, ϕ=4.75 mm) – if this is the case, there is not much to do with the EAR plugs [the auditory canal vary substantially in shapes and sizes; even between the two ears of the same person (!)].

Some researches nowadays prefer using the EAR rings [9] that need to seal the gap between the microphone and ear canal. However, rings pose further problems:

4) the ring + capsule is quite difficult and slow to mount,
5) the ring unfastens easily from the capsule if it is not fitted perfectly,
6) the EAR rings are not manufactured in all possible sizes [see case 3) above],
7) the 'ear plug' is a rather "light" construction of the capsule + ring, i.e., the blockage is less robust as using firm but moldable putty.

For the author, the obvious solution of the above was to use moldable silicone polymer putty [11]. However, while using the sticky putty one needs to be extra careful not to put any silicone into the capsule opening and to apply the *correct amount for the proper blockage*. Also, the repositioning of the capsule needs to be done all over again, i.e., by removing the putty + capsule completely.

3.2. Effect of ear plug type

The use of different earplugs raises also a fair question: does the chosen earplug type affect the measured HRTFs? Considering that the chosen type *may have a tendency* to cause:

8) a deviant microphone position (e.g., too big an EAR plug [or too much silicone putty] may cause the capsule to sit more outwards from the *meatus* entrance), or
9) an insufficient, i.e., leaking, ear canal blockage (e.g., EAR rings are more difficult to mount).

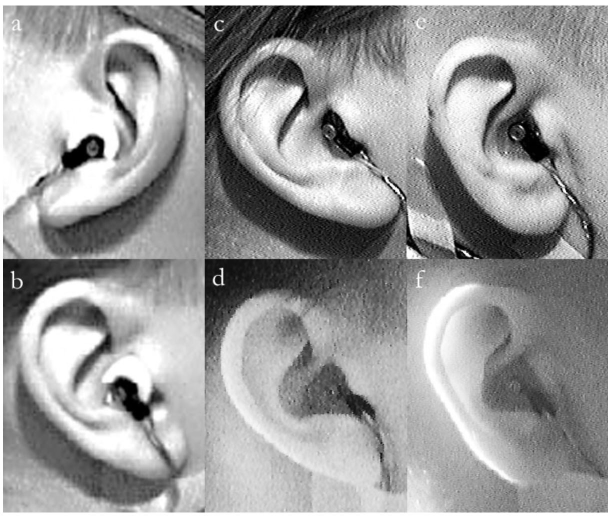

Fig. 1. HRTF repetition measurements, varying putty amount and material, subjects R1 and R2. A) polymer foam (EAR), subject R1 measured on 01/1997, left ear; b) EAR, R1, 01/1997, right; c) silicone putty, subject R1 measured on 02/1997, right ear; d) R1, silicone, 09/1999, right; e) R2, silicone, 02/1997, right and f) R2, silicone, 09/1999, right. For the left ear silicone photos see [3, Fig. 2].

3.2.1. Measurement conditions

The effect of the foam vs. silicone putty was empirically investigated measuring a 28-year-old male (subject *R1*) in two conditions. The test data using the classic yellow EARs was collected from subject at the zero elevation ($\phi = 0°$), see Fig. 1ab. Measurements using the silicone polymer were collected 1) after a three-week break in 02/1997 and 2) in 09/1999. The system was slightly modified during the three-week pause: the absorbent material on the turntable plate was fixed and two coaxial cables ($ø \approx 7$ mm; outputs of the high-quality custom-built microphone preamplifier (UDMPA10, [12]) hanging upwards behind the subject at ~1 m distance were moved to the steel-net floor. However, due to the proper system compensation [8], the cable influence can be considered insignificant. Moreover, same individual microphones (Sennheiser KE4-211-2) were used for the treatments.

3.2.2. Test subject and microphone positioning

Subject *R1* was positioned most accurately following the procedure discussed in [6, 7], and he sat still in the reference position. Fig. 1ab shows the close-ups for the EAR plug insertion and Fig. 1c and 1 d the silicone treatments (02/1997 and 09/1999, respectively) for the right ear; see [3, Fig. 2ab] for the left ear case.

3.2.3. Results

Fig. 2 illustrates the variation (see Section 2.2) between the three measurements of subject *R1*; the difference between EAR and 1^{st} silicone treatment (top frame) and EAR vs. 2^{nd} silicone measurement (bottom frame). The two conditions and both ears indicate a strong difference (±15 dB) above 5 kHz. The curves demonstrate two following diverse phenomena.

1) A more or less *constant "gain change" across all azimuths* (per the frequency band in question) signifies the degree of the auditory canal blockage, as discussed also Section 4.2. Now, it seems that the *silicone yields to deeper antiresonances and less strong peaks to the HRTF characteristics* in comparison to the EAR plug (this is also noted in [7, 8]). What is more, it is likely that the silicone putty seals more efficiently the *meatus*, causing pressure drops in high frequencies (above 7 kHz) and boosts at low frequencies compared to the EAR plug.
2) A smooth direction-dependent shifting in frequency [of the above gain changes] is most evident in the left ear responses, Fig. 2 top. This demonstrates a difference in the predominant capsule position at the blocked *meatus* / *cavum conchae*; see [3, Fig. 4 and text]. The inconstant position is also visible by comparing Figs. 1abcd and [3, Fig. 2ab]. The left ear photographs in Fig.

1a and [3, Fig. 2ab] indicate that the capsule is positioned to the *cavum conchae* midpoint but pointing slightly downwards in the first session (EAR, Fig. 1a), whereas it is aligned horizontally close to the *tragic apex* (edge of *tragus*) in the second case (silicone, in [3, Fig 2 ab]). The right ear photos (Fig. 1b and 2cd) show less positional variation, but still both the ears plugged with the Classic EARs (Fig. 1ab) imply to the practical problems of not being able to fit it exactly to the individual needs, as discussed in Section 3.1.

Based on the above empirical results, it seems evident that the moldable silicone (or corresponding dermatological putty) yields more accurate (and repeatable, [7, 8]) HRTF measurements with an easier mounting procedure than the expanding polymer foam. The effect of experience/carefulness in inserting the microphone + putty (both polymer foam and silicone) is investigated further in [7, 8].

4. Effect of *cavum conchae* blockage

This chapter focuses on the specific effects of varying the degree of the *meatus* blockage, i.e., the *amount of silicone putty used in* sealing *the cavum conchae*. The data is acquired by miniature electret microphones (Sennheiser KE4-211-2, ø=4.75 mm) at the entrance of the ears of subjects *R1* and *R2* (another male of same age, see [3]).

4.1. Collection and quality of HRTF data

The data investigated in this chapter is based on the *__right ear__* *responses of subjects R1 and R2.* The left ear results are investigated in the facing paper [3] of the current triplet study [3-5].

The data was collected using the highest accuracy practically available with real subjects. In [3] it was already demonstrated that no other quality disrupting effects than a) *the small variation in microphone positions* and b) *the degree of the ear canal blockage* should be considered significant. The case a) is discussed in [3].

4.2. Results

The responses of both subjects *R1* and *R2* in Fig. 3 display much less elevation-azimuth combined frequency shifting as the right ear curves show in [3, Fig. 3]. Now, the major findings (reflected with the left-ear results in [3, Section 3.3] indicate the following.

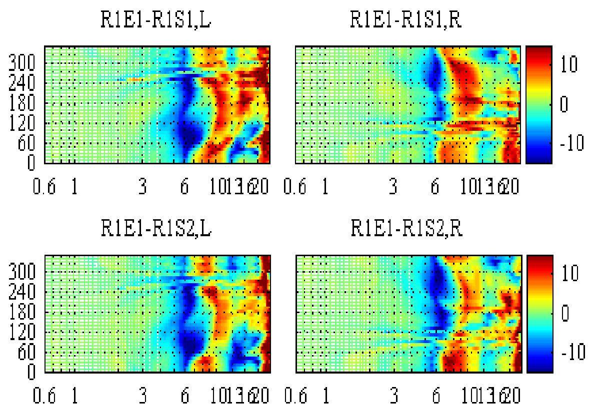

Fig. 2. Effect of earplug, polymer foam (EAR) vs. silicone blocked (θ=0°) HRTFs on subject R1. Above: EAR - silicone (data obtained on 02/1997); below: EAR - silicone (data obtained 09/1999); see also [3] for right ear analysis.

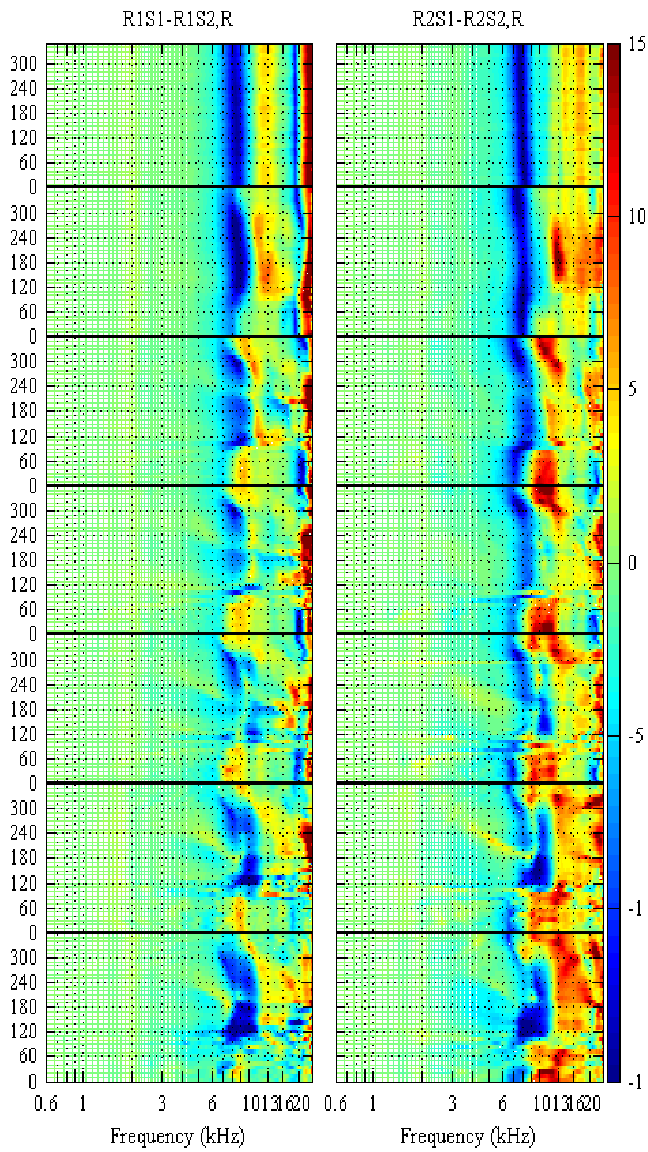

Fig. 3. Effect of silicone blockage on HRTFs, repetition measurements on 02/1997 and 09/1999 using different amount of putty. Left: subject R1 (right ear data); right: subject R2 (right ear data).

1) Subject *R1* demonstrates a strong deviance: a 10-15 dB SPL decrease around 7-11 kHz and a pressure boost up to 15 dB around 9-20 kHz [+ the common level raise over 20 kHz as also in [3, Fig. 3 left hand-side]). The noted difference is greater than the effects of varying the capsule position as seen in [3, Fig. 3 left hand-side].
2) Subject *R2* shows around 7-11 kHz a 5-15 dB pressure drop in the second measurement (+ a similar high frequency boost as in the left ear case [3, Fig. 3 right hand-side]). There is also a minor 5 dB increase around 10-16 kHz.
3) A close investigation of Fig. 1cdef implies that during the first measurements (Fig. 1ce) there has been less putty in the *meatus* than in the later recording. This matter is more obvious for subject *R1* (Fig. 1c vs. 1d) than *R2* (Fig. 1e vs. 1f).

5. Discussion

Based on Section 4.2, it appears that the (right ear) responses in Fig. 3 suffer not only from slightly different microphone positions between repetitions noted above ca. 11 kHz (as discussed in [3]). Namely, the *dissimilar blockage of the meatus / cavum conchae* has caused the moderate to strong (±5..15 dB) pressure drops around 7-11 kHz, as witnessed in Fig. 3. This effect gives further proof for the findings in [7, Section 4.2.4], which is studied further in [8]. The responses at above elevations show that there is a more or less *constant*, i.e., across all azimuths, *difference in sound pressures*. At elevations below 60° these "gain changes" are affected by the minor variations in the capsule positions, so that the superposed (combinatory) end result is no longer direction independent.

The above shows that the *natural resonances* at the (blocked) *cavum conchae*, see e.g., [13, 14], are rigid enough not be altered by the amount of silicone used to block it. This, of course, necessitates that enough putty in general is used – otherwise the leaks from the *meatus*, i.e., auditory canal resonances, will change the resonance behavior of the *pinna*. The combinatory results prove that *different cavum conchae eigenfrequencies* are observed *by changing the position of the microphone capsule* at the blocked *meatus*, which is also shown for the left ear case [3].

6. Conclusions

The second part of the triplet paper [3-5] discussed specific problems in performing blocked *meatus* HRTF measurements. The effect of the earplug, i.e., compressible polymer foam and moldable silicone, was addressed by giving practical considerations verified by empirical results. The silicone putty was found to yield better repeatable HRTF characteristics, and the amount of (silicone) putty used, as long as being sufficient enough, was witnessed to cause overall gain changes, depending on the ear and typically around ±5..15 dB above ~7 kHz. No alterations in the *natural resonances* of the *cavum conchae* were noted due to adjusting the amount of the silicone putty.

7. Acknowledgements

The author wishes to thank the two test subjects for their precious time and the Finnish Cultural Foundation, the Graduate School of Electronics, Telecommunication and Automation and Jenny and Antti Wihuri Foundation for support and numerous researchers for excellent scientific discussions and education for life in general.

8. References

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