Part Va: Effect of Head Movements on Measured Head-Related Transfer Functions

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Abstract

The influences of various *static head poses* and *head movements* in measured *head-related transfer functions (HRTFs)* are investigated in the last part of the current triple paper. A head movement indicates *alterations in the blocked meatus HRTFs* that may be similar to the ones caused by the head statically slanting to the same direction. *Ipsilateral azimuths below 60° elevation (≥ 6 kHz)* are most intensively altered, typically *~1 dB / 1° offset angle*. The most problematic motion is a rapid pivot, e.g. "nodding" with a sleepy test subject, causing time variant characteristics to HRTFs.

1. Introduction

Head-related transfer function (HRTF), e.g., [1, 2], measurements are subject to many kinds of disrupting matters. This paper is the last part of the triplet study [3-5] focusing to yet another common aspects, i.e., the effects of *incorrect head position* and *simultaneous head movements* in measured HRTFs. These quality-related issues are discussed also in [6-8].

1.1. Means of analysis

All measurements were done using Sennheiser KE4-211-2 microphones at the entrance of the silicone puttied ear canals, i.e., at the *cavum conchae* in the *blocked meatus*, carefully positioned by a well-experienced experimenter (the author). The applied point-to-point dB-magnitude difference plots show lucidly the variation of the repetitive measurements, which are 0.1 octave smoothed, but not system compensated, unless the data was obtained on different days (Section 2.2.2).

2. Effect of incorrect head posture

Proper HRTF measurements necessitate a routine-like, accurate and fast, procedure for positioning the test subject the *reference position*, so that the interaural axis matches the horizontal level (δ=0°) and *nasion* points towards the frontal median plane, i.e., zero azimuth (θ=0°). Generally, the subject would *change the head posture* due to impatience, insufficient headrest or (visual) feedback. But the reason might also be health-related: short-term muscle tensions in the neck or rarely even neurological disorders, causing also involuntary movements [9].

The head can be slanted to different directions, i.e., parallel to the main planes [1]: a) *pivoted* (median plane), b) *tilted* (frontal plane) or c) *rotated* (horizontal plane), or any combination thereof.

2.1. Effect of tilted head (+ accuracy of positioning procedure for real subjects)

The accuracy of (re-)positioning a human subject and the effect of a minor constant head tilt is investigated using data from a 25-year-old male (*R3*), see Fig. 1. The microphones were kept untouched at the *meatus* during the short 5-minute break between the two sessions.

The first run took 35 minutes (θ=0°:10°:360°), during which the subject had *his head tilted* ca. 5° to the left. [He changed to his 'normal' slanted pose just before the data collection.]. The head position was corrected straight in the second trial, performed in 40º-azimuth intervals in 9 minutes. The subject sat very still during both sessions, without any head movement during the data acquisition.

In Fig. 2, the dB-magnitude differences between the two data sets (θ=0°:40°:320°) indicate *generally an outstanding repeatability, typically only ±1..2 dB* variation in the whole frequency range, except the ipsilateral directions. This proves the high accuracy of the (human) *test subject and microphone positioning procedure*, which is also proven even better (≤±0.5 dB) for dummy head measurements [8]. Also, there are no alterations extending to low frequencies, proving the absence of head movements during measuring (see Section 3.1).

The remaining factors are caused by the changed head position, i.e., the minor head tilt in the first sessions indicates the following.

1) The HRTFs are sensitive to *head tilts*, even a *minor 5º tilt causes moderate, ca. ±5..8 dB* magnitude variation above ~2 kHz, and *even ±10* (θ<60°) *dB above 6-7 kHz, at ipsilateral sound incidents*. The effect is symmetrical to the median plane (δ_{left} ≈ 280±40º; δ_{right} ≈ 80º±40º) and it seems to be less prominent at the ear to which direction the head is tilted.

Fig. 1. Test subject R3, tilted vs. straight head position.

2.2. Effect of pivoted head

The pivoted head position is first studied with a simulated case and then with real data containing also other HRTF quality disrupting matters; see [3, Section 2.1].

2.2.1. Pivoted head position (estimated)

The effect of a pivoted head position is *estimated* by subtracting the subject's measured data (θ_{ref}, δ_{ref}) from the same data but chosen from the angle of the desired *vertical offset*, i.e., ($\delta_{comp}=\delta_{ref}+\delta_{\Delta}$, $\theta_{comp}=\theta_{ref}$).

Fig. 4 shows the result of this "*simulated*" downward head pivot of 15° ($\delta_{comp}=\delta_{ref}+15°$; $\delta_{comp}\leq 30°$) and 30° ($\delta_{comp}=\delta_{ref}+30°$; $\delta_{comp}\geq 60°$), using measured data from a 25-year-old male subject *KR*, see Fig. 3 (right-hand side). Well similar trends can be calculated from other subject's (and dummy head) data, and hence the effect can be summarized as follows.

1) A *notable head pivot (15°) alters semi-strongly (±5..15 dB in magnitude) the HRTF characteristics*, and approximately bilaterally symmetrically. The *ipsilateral directions* ($\delta_{left}\approx 270\pm 40°$; $\delta_{right}\approx 90°\pm 40°$), especially at low elevations ($\delta\leq 0°$), *witness ~±10 dB pressure changes at a wide frequency range (~2-24 kHz).* The same is also noted for all azimuths ($\delta\leq 0°$) at 2-4 kHz and for all directions above 16-20 kHz. At the low elevations there is also typically more change in the anterior than the posterior directions.
2) At the remaining directions the HRTF characteristics shift smoothly in frequency, mostly above ~6 kHz. The higher the elevation is, the smoother and less powerful the alterations are.

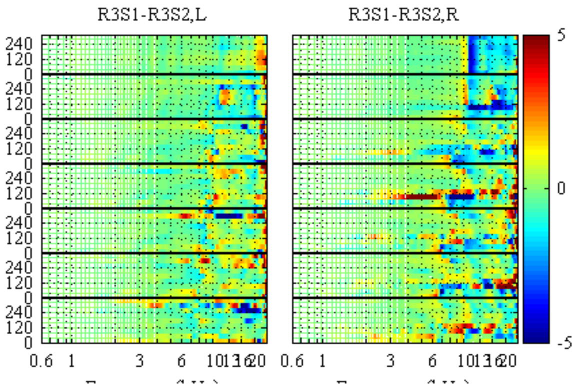

Fig. 2. The effect of a ~5° tilted head, data measured from subject R3. Note the smaller scale (± 5 dB) and sparser horizontal resolution (θ=0°:40°:320°).

Fig. 3. Subject KR, pivoted vs. straight head position. Note also the changed hairstyle.

2.2.2. (True) head pivot with combinatory effects

A strong (~20°) head pivot was encountered with one set of measurements from the previous male subject; see Fig. 3 (left-hand side)**.** Next, this data is compared to his reference measurements (Fig. 3, right-hand side) that were performed 5 weeks afterwards.

In both cases the well-experienced subject (author) placed the microphones + putty to his ears himself in front of a mirror. The same assistant experimenter carried out the semi-automated measurements, following carefully the simultaneous procedural instructions from the author [6, 7].

Fig. 5 demonstrates the differences between the two system compensated measurements. Next, these plots illustrate the complex *combinatory effect* of the *pivoted head, changed hairstyle* and slightly *varying microphone position*.

1) The top elevation (δ = 90°) right ear plots show a variance less than ±3 dB, on the whole frequency band (!). This indicates that the head and right microphone + putty have been placed well to the same position in the two sessions [4, Chapter 5].

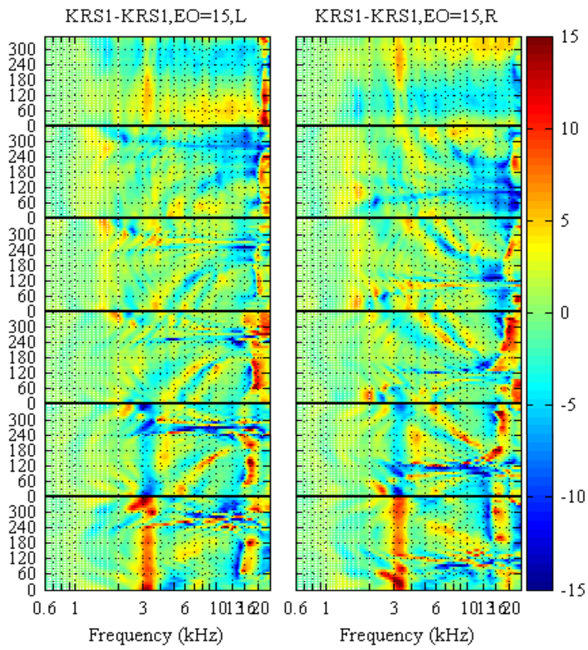

Fig. 4. The effect of a 15/30° downwards pivoted head pose, calculated from measurements (subject KR).

2) The left ear responses (δ = 90°) show a total variation of ~±5 dB (>8 kHz) and ~10 dB above 13 kHz, indicating that the left capsule has not been placed exactly at the same place in the two sessions, but still relatively well; see also [3, 4].
3) Based on author's other studies [8, 10], the double-altered hairstyle would cause relatively minor (≤±7 dB) variations at ipsilateral directions (≥3-5 kHz).
4) The *pivoted head position has the strongest effect* that is now combined with the other above factors to yield large variations of ~±15 dB beyond the *ipsilateral directions.* The end result involves similar characteristics as the simulated head tilt presented in Section 2.2.1.

2.3. Rotated head position (estimated)

The rotated head position effect is *estimated by using an azimuth offset* (θ_Δ) to the measured HRTF data: ($\delta_{comp}=\delta_{ref}$; $\theta_{comp}=\theta_{ref}+\Delta$).

Fig. 6 shows the difference of a 10° horizontal offset (towards the left ear: $\theta_{comp}=\theta_{ref}+10°$), applying Cortex MK II dummy head data. Further analysis reveals well similar results with other subjects and also with the rotation to the opposite direction (leading to the reverse of sign). This confirms the following.

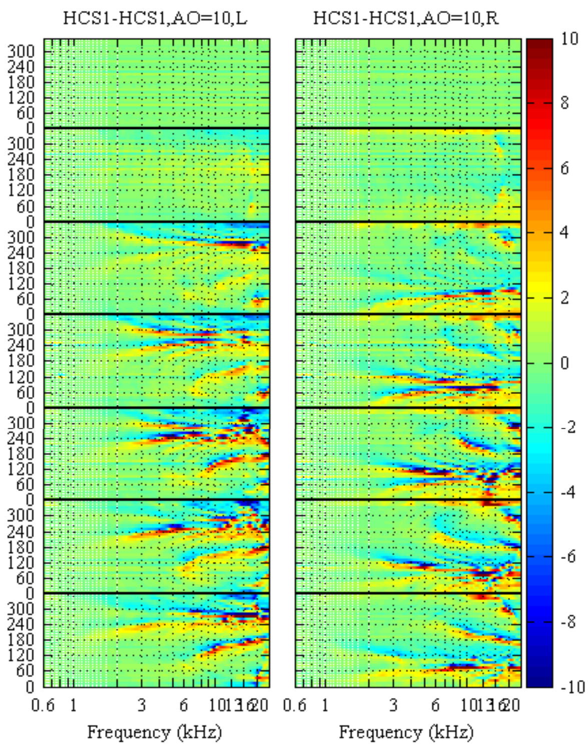

Fig. 6. The effect of a 10° (to the left) rotated head pose, estimated from dummy head (HC) measurements.

1) Fairly rotated head (θ_Δ=10°) *causes moderate variations* (±10 dB) to the HRTF characteristics *above 2 kHz at ipsilateral sound directions excluding the above direction*, i.e., (δ<90°, $\theta \approx \theta_{right,left}$ ±40°).
2) The more the head is rotated, the stronger and broader is the alteration: e.g., a strong 20° horizontal pose will cause more powerful variation (maximal ±15..20 dB) to the HRTF characteristics, starting already above 1 kHz at ipsilateral sound directions, excluding the above direction, i.e., (δ<90°, $\theta \approx \theta_{right,left}$ ±150°).

Other studies [8, 10] indicate that the effect of the rotated head position resembles somewhat the alterations caused by different hair/styles on HRTF characteristics.

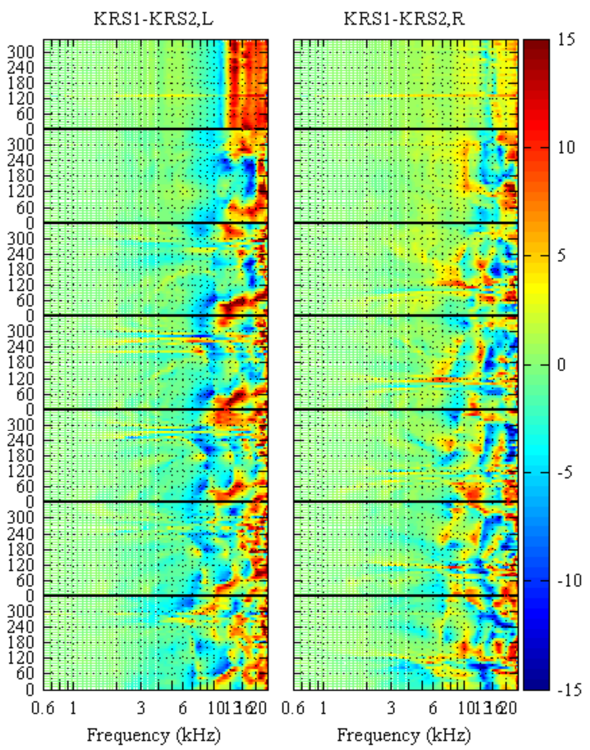

Fig. 5. The fusion effect of a ~20° downward head pivot + hairstyle modification + possible microphone displacement, measured at the silicone blocked meatus (subject KR).

2.4. Rotated and tilted position (estimated)

The head position is typically not slanted to one axis only. Adding both vertical (δ_Δ) and horizontal (θ_Δ) offsets, the effect of both pivoted and rotated head position may estimated in a similar manner as previously: ($\delta_{comp}=\delta_{ref}+\delta_\Delta$, $\theta_{comp}=\theta_{ref}+\theta_\Delta$). This superposes the results seen in Figs. 4 and 6 [plots not shown do to space limitations], which yields to the following.

3) The 15° head pivot mostly overrides the 10° rotation effect. Slightly larger horizontal offset (θ_{Δ}=20°) has generally a weaker affect except a similar one at the mid-elevations (δ_{comp}=15°, 30°).

3. Head movements during HRTF measurements

The effect of *simultaneous head movements* (occurring *during the actual probing* stimulus) in the HRTF measurements is very complex to investigate. The influence depends on many factors, such as the (robustness of the) 1) used *stimulus type* (note, e.g., [11]), their (kinetic) 2) *amplitude,* 3) *acceleration,* 4) *direction*, and 5) *occurrence in time* in relation to the probe.

3.1. Head shaking (sideways)

The random head shaking of a nervous 32 years old male (subject *R4*) is studied with two successive measurements (θ=0°:10°:60°). The subject wore the microphones fixed during a 5 min pause, after which he was re-positioned accurately. In both the sessions he moved his head almost constantly, which was lucidly monitored by the experimenter (author). The *effect of the movements (Δ=±5°..10°) is rather small, only ca. ±5 dB above 6 kHz* indicating a rotational head shaking, as anticipated from the previous results; see Fig. 7. This result is well in line with the synthetic rotation movements discussed in [11].

3.2. Head pivoting (nodding)

Typically, heavy head nodding occurs infrequently with a sleepy subject: the person will come to notice her/his involuntary movements and pause/stop doing it. Even so, this is very troublesome, because the rapid head pivoting *deteriorates effectively the measured HRTF*, which is noted *also in the low frequencies* signifying time variant behavior; see, e.g., [7, Figs. 28, 30, 32, 36]. This over-frequency attribute is not witnessed in the other disturbing matters in HRTF acquisition [3, 4, 8].

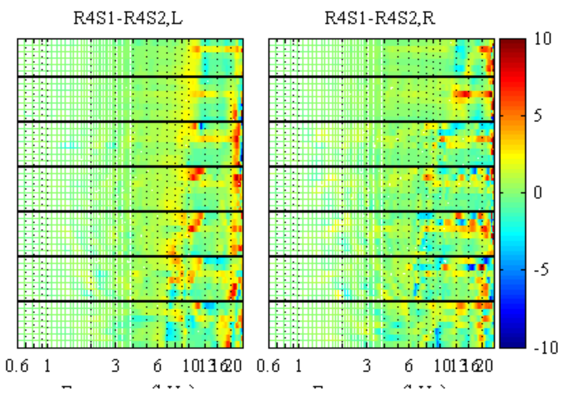

Fig. 7. The effect of continuous head shaking during HRTF measurements, subject R4; θ=0°:10°:60°.

4. Discussion & conclusions

A more complex head movement shows similar influence to the HRTF data as a simpler fixed head pose to that direction. The end result depends on various attributes, but roughly generalizing, the most sensitive directions are the ipsilateral azimuths (δ≤60°), affected mostly above 6 kHz. The pivoted head pose (or pivoting movement) seems to cause the strongest / most wide-ranging alteration, though a strong tilting effect sould be studied further. In overall, a slanted head position / head movement is likely to change the HRTF characteristics, approx. 1 dB / 1° offset angle.

The consequences of *large* head movements are obvious: they will practically destroy the measured HRIR that will no longer be linear and *time invariant* (LTI). The key factor is the actual movement magnitude, both in time and space. A fixed head pose is another matter. Basically, it alters the torso reflections, which have been found to be significant for the sound localization [12]. The changes described in this paper are significant in the absolute sense, but it could still be argued if they are perceivable. It might be that the *pinna cues* (or the *cavum conchae eigenfrequencies* [13, 3, 4]) being stronger, i.e., "*hardwired*" to the brain, *would overcome* the presented head posture effects – except (and perhaps?) if head movements would be done deliberately, with full attention of the listener [14].

Concerning the quality of the HRTF measurements, the best solution is to devise good enough a system and method (+ use able subjects) that the head movements and incorrect positions would be avoided altogether.

5. Acknowledgements

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6. References

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