The osseous external auditory canal
van Spronsen, E.

Citation for published version (APA):
The effects of alterations in the osseous external auditory canal on perceived sound quality

E van Spronsen, P Brienesse, FA Ebbens, JJ Waterval, WA Dreschler

ABSTRACT

Objective
To evaluate the perceptual effect of the altered shape of the osseous external auditory canal (OEAC) on sound quality.

Study design
Prospective study

Subjects and methods
Twenty subjects with normal hearing were presented with six simulated sound conditions representing the acoustic properties of six different ear canals (3 normal ears, and 3 cavities). The six different real ear unaided responses (REURs) of these ear canals were used to filter Dutch sentences, resulting in six simulated sound conditions. A seventh unfiltered ‘reference’ condition was used for comparison. Sound quality was evaluated using paired comparison ratings and a Visual Analogue Scale (VAS).

Results
Significant differences in sound quality were found between the ‘normal’ and cavity conditions (all p<0.001) using both the seven-point paired comparison rating and the VAS. No significant differences were found between the reference and ‘normal’ conditions. Sound quality deteriorates when the OEAC is altered into a cavity.

Conclusion
This proof of concept study shows that the altered acoustic quality of the OEAC after radical cavity surgery may lead to a clearly perceived deterioration in sound quality. Nevertheless, some questions remain about the extent to which these changes are affected by habituation, and by other changes in middle ear anatomy and functionality.
INTRODUCTION

The external auditory canal is known to have a complex anatomy with considerable inter- and intra-individual variability (1). The auditory canal plays a role in the transfer of sound from the concha to the tympanic membrane and acts as a resonant tube (2). Several manuscripts have reported a change in resonance acoustics when the osseous external auditory canal (OEAC) is modified surgically (3-6). The creation of a wide OEAC (as is the case with a radical cavity) was shown to decrease the resonant frequency substantially and alter the peak amplitude significantly (3). Although these changes have been reported several times in the past, it seems that no attempt has been made to correlate objective measurements with the subjective sound quality of this altered sound. As suggested by Satar et al., an evaluation of the perceptual consequences could be interesting (7). The fact that some of our patients reported changes in hearing after surgery even when the audometric evaluation of both speech intelligibility or pure tone sensitivity remained the same makes the evaluation of this possible explanation even more worthwhile. As these effects may affect ‘everyday’ sound perception in patients, it is important to determine whether these changes are clinically relevant. If changes in sound perception are significant, otologists should be aware of these effects when planning therapeutic interventions or, alternatively, disregard them if there is no significant change in sound quality.

The purpose of this study was to test whether and to what extent sound quality is affected by changes in the acoustics of the external auditory canal and whether these changes explain our clinical observations and are therefore clinically relevant.

PARTICIPANTS AND METHODS

Subjects

Twenty individuals with normal hearing were selected. The group was comprised of 14 (70%) female and 6 (30%) male participants with an average age of 36.8 years (median 32.3, range 21.4 to 61.8 years). Their hearing thresholds were 20 dB HL or better at 0.25, 0.5, 1, 2, 4 and 8 kHz. All participants were healthy and had no history of ear disease. No CT scans were made as there was no clinical need to do so. Three patients (1 female, 2 males) who had undergone a canal wall down procedure 15 years or more prior to this study due to cholesteatoma agreed to participate in this study. The cavities were all dry (Merchant grade 0)(8) and had been properly cleaned before measurements were performed. CT images of these cavities were acquired during regular clinical care. Three other volunteers (1 female, 2 males) with no history of ear disease and normal ear canals determined by regular otoscopy agreed to participate as normal controls.

Simulation of the acoustic properties of six individual ear canals

The acoustic properties of the ear canal can be characterised by measuring the real ear unaided response (REUR) (9). This response is measured with a probe microphone inserted into the external auditory canal and it shows the sound pressure level at the eardrum after
the presentation of a well-defined broadband sound stimulus. Differences between individual REURs therefore represent differences in the acoustic properties of individual ear canals. For instance, the acoustic effect of an ear canal of a radical cavity can be simulated in a normal ear canal by filtering the incoming sound stimulus using the difference between the REUR of a normal ear and the REUR of a cavity ear. In a normal ear, this filtering results in the same distribution of sound pressure at the eardrum as in the original radical cavity.

We made recordings of Dutch speech (two male-spoken and two female-spoken sentences based on the VU98 sentence material (Versfeld et al. (9)), filtered to simulate the acoustic properties of three normal ear canals and three radical cavity ear canals. The REURs of the three ‘normal’ ear canals and the three radical cavities were measured in the non-participating volunteers using the REM module of the Affinity 2.0 Hearing Aid Analyzer platform (Interacoustics, Denmark). [Figure 1] shows the REUR results for three healthy individuals with normal ear canals and three patients with a radical cavity. The results are presented as real ear unaided gain (REUG: the difference between the incoming broadband stimulus and the REUR). In addition, CT images are shown of the three cavities at the level of the oval niche.

Six filters (simulated conditions) were built on the basis of the differences between these six REUGs and the average REUG of a normal adult ear canal (see Table 4.6 in Dillon H, page 110 (10)). The seventh ‘reference’ condition consisted of the unfiltered speech material.

Perceptual evaluation
The perceptual evaluation experiment was performed with a paired comparison category rating with two fragments (‘A’ and ‘B’) in accordance with ITU-T 1996. Participants were asked to use a seven-point scale to indicate which fragment sounded more natural. These fragments consisted of the six conditions (three ‘normal’ ears and three cavities) and each filtered condition was compared with the unfiltered reference condition. All conditions were presented using two male-spoken and two female-spoken sentences. Each condition was measured twice: once with the filtered sentence as ‘A’ and the reference sentence as ‘B’, and once in the reverse order. These 48 paired comparisons, together with 4 control comparisons in which the seventh unfiltered condition was compared with itself, resulted in a total of 52 paired comparisons being presented in random order.

The paired comparison category rating was followed by VAS scoring to evaluate the ‘overall’ sound quality of the seven conditions, with 0 being the worst possible outcome and 100 the best. Once again, the seven conditions were presented in random order by playing four different Dutch sentences.

All the speech material was presented in free field at a level of 65 dB(A) using a loudspeaker in front of the listener (0° angle).

Statistical analysis
Statistical analysis was conducted using SPSS 16.0.2 (Chicago, IL, USA). Data are expressed as numbers. The paired comparison rating results are stated on a seven-point scale ranging
The effects of alterations in the osseous external auditory canal on perceived sound quality

from +3 (the simulated ear canal, or filtered, signal sounds are much more natural than the reference, or unfiltered, condition) to -3 (the reference condition sounds much more natural than the simulated ear canal). A score of 0 means that no noticeable difference in naturalness was perceived between the two conditions. Mann-Whitney U testing was performed to check for significant changes from baseline in the VAS scores. ANOVA multivariate analysis was used to determine the effects of subject, condition, and gender of the speaker on the results. A Bonferroni correction was applied to account for multiple comparisons. \( P \) values of less than 0.05 were considered statistically significant.

Figure 1. Measured Real Ear Unaided Gain (REUG) of all conditions: three normal ear canals (N1, N2 and N3) and three ear canals with a radical cavity (C1, C2 and C3, dark lines). In each window the average adult REUG ia also depicted (Dillon) (light line). The REUG data are depicted on the same scale from 100 Hz to 7000 Hz on the frequency x-axis, and -25 to 25 dB(gain) on the y axis. The cavity conditions are shown with the according CT scan image in the axial plane using the oval window niche as reference point.
RESULTS

Paired comparison ratings
The ANOVA analysis did not identify a significant difference in perceived sound quality between the male and female speakers (p=0.19). However, the different conditions significantly affected outcome, as can be seen in [figure 2]. When the various conditions were compared pairwise with the reference condition, all the cavity conditions were perceived to be significantly less natural. No significant difference was seen between the three normal conditions and the reference condition since their rating scores were not significantly different from 0. In a pairwise comparison, all cavity conditions were found to be significantly less natural than the normal conditions (all p<0.001). The second cavity condition (C2) was rated as being significantly less natural than all other conditions (all p<0.001).

VAS scores
The seven conditions presented are shown in [figure 3]. No significant difference in VAS scores was observed between the reference and normal conditions (all p>0.1). However, there were

Figure 2. Results of the paired comparison ratings. Scores range from 3 to -3 on a seven point scale. A score of 3 means that the simulated ear canal acoustic c.q. filtered signal sounds much more natural than the reference c.q. unfiltered signal. A score of -3 denotes a clear preference in naturalness for the unfiltered signal. A score of 0 means that there is no noticeable difference in naturalness between the two signals. Bars denote de 95% confidence interval for the mean.
The effects of alterations in the osseous external auditory canal on perceived sound quality

The clear, significant effects between normal conditions and cavity conditions strongly support the hypothesis that alteration of the OEAC can result in a clinically relevant distortion of sound quality, which may be less natural or of poorer quality. This supports our hypothesis that this phenomenon is the cause of our clinical observations. The cavity conditions were found to generate poorer overall quality as compared with normal conditions and were perceived to be less natural. An unexpected, interesting finding was that significant differences were also found in the cavity conditions. These differences could possibly be explained by the shape of the cavities: the volume of the bowl or the size of the meatoplasty could cause this wide variance in the alteration of the acoustic properties. Further research to determine the cause could be useful in evaluating which properties could be beneficially altered (in other words, the properties that have a minor impact on perceived sound quality). As the field of otology is moving towards the usage of obliteration techniques and Satar (7) has shown that obliterated cavities can achieve near-normal resonance frequencies, this could also be a condition that requires further evaluation.

Figure 3. VAS evaluation of the perceived quality of the presented sound per condition. REF (black colour): reference N1-3 (Blue colour): ‘Normal ear conditions’ C1-3(Red colour): Cavity conditions. NS: not significant compared to reference, * significant difference with reference and normal conditions (p<0.01), ** significant difference with all conditions (p<0.01)
Intelligibility of speech is not affected. Although there were clearly audible differences in sound quality, the content of all the sentences was easily understood. This is in line with earlier work in the field of audiology as it is known that the speech spectrum can be altered quite extensively before intelligibility is affected. One could debate whether a ‘distortion’ of sound without any loss of speech intelligibility is clinically relevant. Nevertheless, our clinical observations do suggest that this phenomenon is indeed clinically relevant.

We only explored the most ‘radical’ alterations resulting from changes in the shape of the OEAC using radical cavities in our study design. Nevertheless, other surgical alterations to the OEAC (and subsequently the changes in resonant frequency) such as canalplasty, meatooplasty and reconstruction of the OEAC in revision radical cavity surgery can elicit similar significant effects on sound. Further research in this field is therefore advisable.

The VAS score and paired comparison scoring for the assessment of the overall quality of sound could be seen as crude instruments since sound quality can be broken down into many subcategories (such as loudness or sharpness). Even so, we feel that this is a valid approach to relevant testing in outpatient clinic practice on a regular basis because the answers to general questions of this kind are important as primary outcome parameters for clinical success. Both five-point Likert scales and VAS scores are regularly used for subjective measurements of complaints.

A possible limitation of this study could be that we looked at more female than male subjects. Even so, we believe that this gender discrepancy has not had a significant impact on the outcome of our study. Using normal-hearing subjects does give rise to some points of discussion. We know that the alteration of external ear acoustics is not the only effect that surgery can have. It has been argued that a change in middle ear volume in canal wall down procedures and the type of tympanoplasties/ossicular chain reconstruction performed could also play an important role in perceptual hearing (3,11,12). However, our study did not consider these possible mechanisms since we wished to focus exclusively on the changes in perceived sound quality resulting from the changes in the shape of the OEAC.

It is possible that using radical cavity patients as their own control could reveal whether sound quality is influenced by habituation in patients. Our study design did not look at possible habituation. Even so, if there is habituation, this could render our findings less useful since adaptation to ‘poorer’ sound quality could mean that differences experienced at the outset will no longer be clinically relevant in the long term, even when patients perceive clinically relevant primary deterioration. Further research looking at habituation effects would therefore seem to be necessary.

**CONCLUSION**

Our proof of concept study shows that changing the shape of the OEAC not only has an impact on sound quality but that it also leads to poorer perceived sound quality when a cavity is drilled. The changes in resonant frequency will elicit a clinically-relevant, perceptual ‘distortion’ of sound and this should therefore be considered when altering the shape of the OEAC. Since
some aspects are still unclear, further research is needed to make these findings more applicable in current clinical practice.
REFERENCES


