Evaluating Mechanical Comfort of Ear Tips: An Experimental-Computational Approach

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Abstract

The mechanical comfort of in-ear devices is integral to their usability. Particularly for hearing protection devices intended for long-term wear, discomfort can lead to inconsistent or improper use, thus undermining their purpose. We have tested a three-pronged approach for evaluating ear tip comfort: the utilization of 3D ear canal data to create ear canal surrogates, the development of finite element models of ear canals, and the collection of user feedback.

In our trial, 3D printed models of ear canals, obtained from 3D scan of ear impressions, were used as surrogates. Equipped with load cells, these surrogates measured forces generated from the insertion of commercially available ear tips. For instance, we observed that, while similar in foam stiffness, the ear tip with a larger and more rigid sound bore exerted nearly twice the force on the ear canal surrogate. In blind trials for a period of 2 hours, 60% of the participants (n=7) deemed the same ear tip as less comfortable for long-term wear. However, feedback varied widely, likely due to individual differences in ear canal geometry and tissue mechanics. Notably, most users did not favor any of the tested tips for extended wear periods, highlighting the need for design improvement. Finite element simulations enabled an in-depth investigation of the deformation behavior of ear tips and the identification of the pressure hotspots within the ear canal depending on the characteristics of the ear canal and tip such as material, geometry, and sound bore dimensions. Further, the simulations proved capable of detecting folding that affects some types of ear tips.

By integrating computational mechanics, mechanical testing, and 3D-printed ear canal surrogates, our platform quantifies the user experience and allows parametric ear tip design to optimize comfort. Our next steps include expanding our user population and improving our understanding of ear tissue biomechanics.

Keywords: Ear Tip Stiffness, Finite Element Analysis, Hearing Protection, Materials, Mechanical Comfort