Esteem Middle-ear Implant Users' Perception of Own-Voice Loudness

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Research Questions

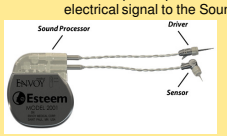
The Esteem® active middle-ear hearing implant operates via the air conduction pathway of the auditory system. However, bone-conducted signals also receive some amplification, probably via the inertial mode of bone conduction, in which the vibration of ossicles is detected by the implanted Sensor. Some recipients of the Esteem implant report their own voices as uncomfortably loud, which can impact overall satisfaction with the device. This study was undertaken as an initial attempt to characterize the relative loudness of own-voice perception in this population.

Research Questions:

1. **How do Esteem users judge the relative loudness of their own voice, individually and as a group?**
2. **Does relative bone conduction gain provided by the Esteem for an individual listener relate to perceived own-voice loudness?**
3. **Do subjective ratings of own-voice loudness agree with loudness-matching measures?**

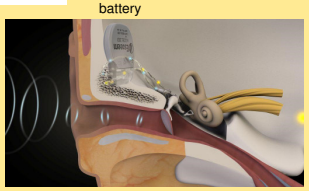
The Esteem System

- The Esteem is a totally implanted, active middle-ear device designed to augment hearing for adults with moderate to severe sensorineural hearing loss.
- No external components: the Esteem uses two piezoelectric transducers:
  - **Sensor -** picks up eardrum's vibrations from incus; transmits an electrical signal to the Sound Processor



- **Driver -** uses processed electrical signal to mechanically drive stapes
- Implanted **Sound Processor** filters and amplifies signal, and also houses a lithium-iodide battery

- FDA-approved in 2010
- Nearly 1000 individuals implanted in the US and Europe



Procedure

Two-interval forced choice procedure

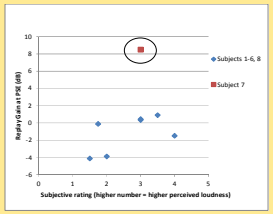
- Subjects repeated "pah" at a natural speaking rate and level for approximately 3 seconds (*listening-while-speaking* interval), then waited for immediate replay of their speech (*listening-only* interval) via insert earphone.
- Subjects' task was to compare loudness of live and replayed speech, identifying which interval was louder by selecting appropriate response on the screen, "First" or "Second."
- No feedback was provided.

Double track, adaptive up-down gain changes

- Trials grouped in two tracks, ascending (starting with an attenuated recording) and descending (starting with an amplified recording), randomly initiated and presented
  - Based on the subject's response, gain on the speech replay was increased or decreased adaptively in 1 dB steps
  - Test ended when criterion of 10 reversals per track reached
- Average gain on the final six reversals in each track (12 gain values in total) was termed the **point of subjective equality (PSE),** a measure of the level difference between live and recorded speech.
- Subjects completed two practice runs; data was included from six tests for each subject (exception: two subjects, E3 and E4, did not achieve 10 reversals on all tracks, so their results are based on five and four tests, respectively).

Discussion

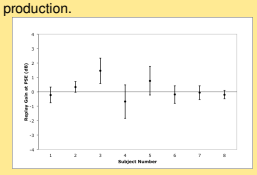
- More than half of the Esteem users behaved like HI subjects (PSE near 0 dB). Two subjects behaved like NH subjects (PSE in negative range, consistent with acoustic reflex). There is no obvious interpretation of this finding. It could reflect response bias -- or it may be that the calculated PSE actually underestimates the magnitude of deviation from zero in the negative direction.
- No systematic relationship was found between individual BC gain and PSE for these listeners.
- Subjective scale was administered; subjects rated relative own-voice loudness on a scale of 1 - 5, with 1 = "quite a bit softer than others' voices", 2 = "somewhat softer than others' voices", 3 = "about average", 4 = "loud, but tolerable," and 5 = "unbearably loud"



- Trend toward agreement between subjective scaling of own-voice loudness and PSE (excluding the outlier) – the lower the subjective rating, the lower the replay gain at PSE.

Introduction and Background

- Own-voice issues are not uncommon among new users of hearing aids. With closed-fit hearing aids, occlusion effect can be a cause -- bone-conducted sound from vocal production leaks into and is trapped in ear canal by the hearing aid and is transmitted to the cochlea via air conduction.
- Recipients of the Esteem middle-ear implant also often report their own voices as seeming loud. In this case, however, it cannot be due to the occlusion effect, since there is nothing blocking the ear canal.
- **Because the Esteem system apparently amplifies bone-conducted (BC) in addition to air-conducted (AC) sound, could this additional amplification of BC energy produced by vocal productions add significantly to the perceived loudness of one's own voice?**
- Previous studies of BC relative to AC sensitivity of one's own voice (von Békésy, 1949; Pörschmann, 2000; Reinfeldt et al., 2010) have shown that the relative perception of BC and AC parts are of approximately equal importance, but frequency dependent.
- Barac-Cikoja et al. (2011, 2012) reported on a method for investigating relative loudness of speech feedback during speech production that involved matching the loudness of live speech and its recorded playback.
- Results with normal-hearing (NH) subjects (Barac-Cikoja et al., 2011) showed that for most subjects, the speech playback had to be significantly attenuated in order to match the loudness of live speech, in spite of the fact that live speech includes an additional bone-conducted component that is absent from the playback. That is, they perceived live speech as softer than its level-matched replay. This finding was interpreted to be due to the effect of the acoustic reflex during speech production.



- In contrast, most of a group of eight listeners with severe to profound sensorineural hearing loss perceived the two as equally loud (see figure at left).

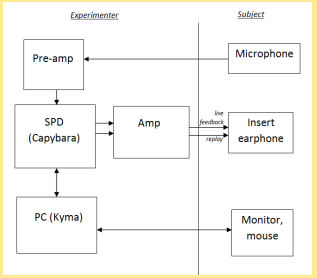
Subjects and Instrumentation

Participants

- Eight adults with an Esteem middle-ear hearing implant (age range: 51 - 89 years; median = 66.5 years; one female, seven males)
- Subjects were paid for their participation
- Subjects used their Esteem at typical everyday-use settings
- Approval for study obtained from University of Minnesota IRB

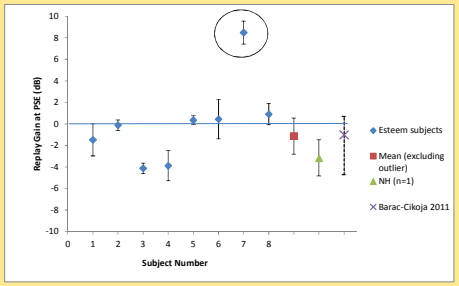
Instrumentation

- Subject's speech recorded with omnidirectional microphone (Sennheiser MKE 2- 4 Gold-C) placed above non-Esteem ear
- Microphone output amplified (402-VLZ3 Premium Mic/line mixer) and routed into SPD (Capybara 320, Symbolic Sound Co) for experimental manipulations
- Output of Capybara sent through Hafler P1000 amplifier, presented monaurally via insert earphone to subject's Esteem ear
- Kyma X (Symbolic Sound Co) software controlling Capybara provided automated presentation of visual prompts, registered subject's responses, performed adjustment of gain values, and recorded data
- Testing conducted in audiometric testing booth



Results

Results are displayed in the figure below. Error bars indicate 95% CI



- **Five subjects' PSE was not significantly different than 0**, suggesting that they perceived live speech (*listening-while-speaking* interval) as equally loud as its level-matched replay (*listening-only* interval).
- **Two subjects showed negative PSE**, suggesting they perceived live speech as softer than its level-matched replay.
- **One subject (circled) had large, positive PSE**, suggesting that he perceived live speech as substantially louder than its level-matched replay. This subject's reliability was considered questionable.
- Also shown:
  - mean of seven of the Esteem subjects excluding the outlier (red square)
  - one normal-hearing (NH) listener from this study (green triangle)
  - Barac-Cikoja's (2011) median of data for NH listeners (purple X); error bars indicate range

Conclusions

- In this study, the majority of these Esteem subjects did not perceive their own live speech as louder than its level-matched replay, suggesting that **the amplification of bone-conducted sound produced by the Esteem system did not result in significant increase in perceived loudness of their own voices.**
- The one outlier is not thought to be representative of typical Esteem recipients. This individual will not tolerate levels of gain approaching prescriptive target, but his subjective rating indicated that his own voice sounds "about average" in loudness compared to others' voices.
- It is possible that even though no systematic relationship was shown between individual BC functional gain and perceived own-voice loudness, information on relative BC gain/frequency response might provide guidance for programming of the Esteem for individuals who subjectively report discomfort with their own voice.
- The issue of bone-conducted body sounds, including own-voice productions, will become increasingly relevant and critical to understand, as more fully-implanted hearing technologies are developed.

References

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