Recording distortion product otoacoustic emissions using the adaptive noise cancelling algorithm

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Some history

Reports published in the mid-1980s indicated that progress regarding early identification of hearing impairment was very slow.

Identification of profoundly deaf children in the US occurred unacceptably too late.

At that time, advances in technology allowed the development of equipment that made possible to establish universal newborn "hearing" screening programs.

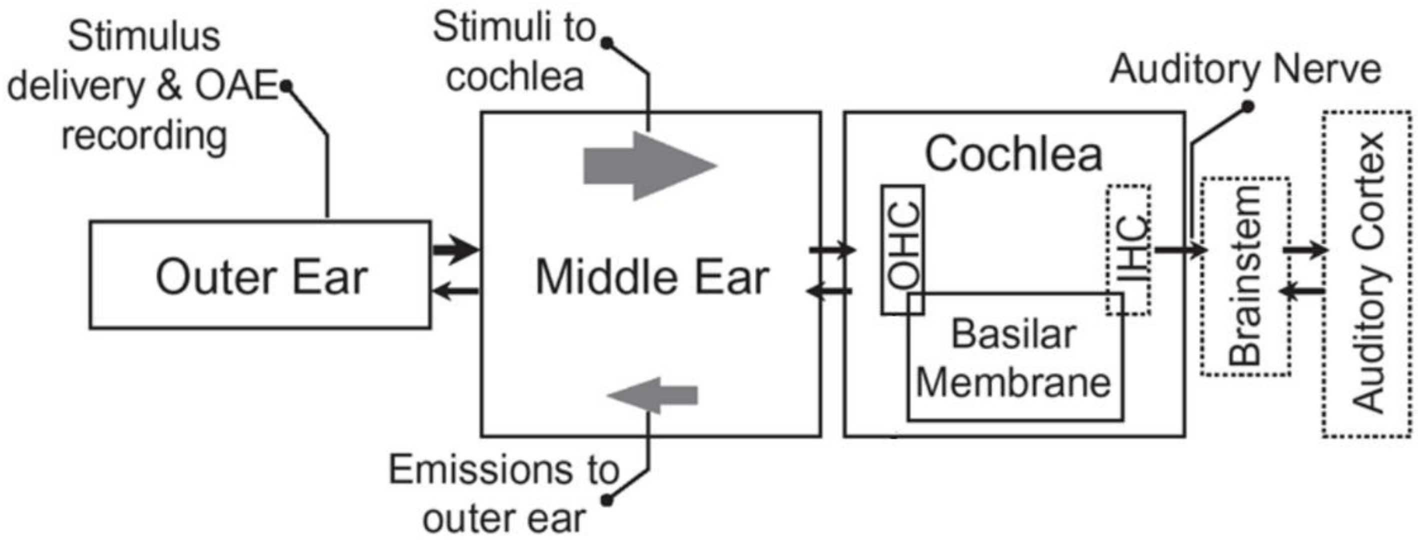
Joint Committee on Infant Hearing (JCIH)
1994 Position Statement

Techniques used to access hearing of infants must be capable of detecting hearing loss of 30 dB HL or greater in infants by 3 months.

Two physiologic measures, auditory brainstem recording (ABR) and otoacoustic emissions (OAEs), show good promise for achieving this goal.

Specific characteristics of test performance for ABR and OAE have not been fully defined in universal infant hearing detection applications.

Otoacoustic Emissions (OAEs)



OHC: outer hair cell

IHC: inner hair cell

Adopted from Dhar & Hall (2018)

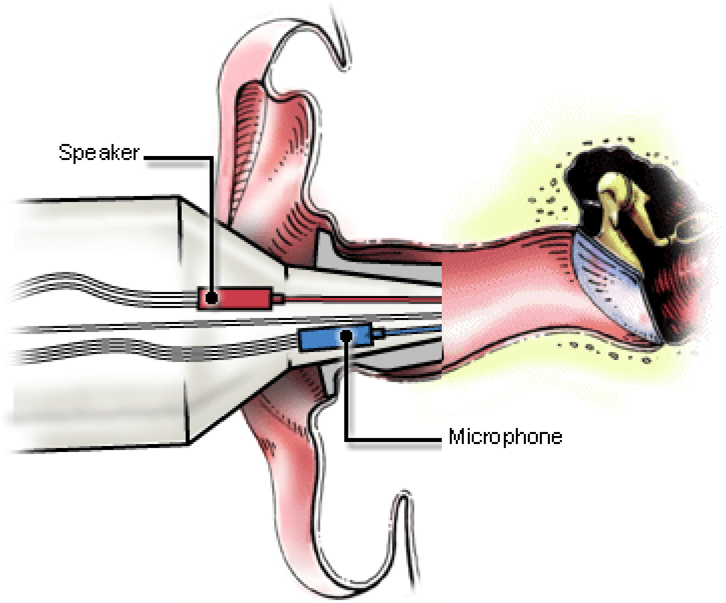
An acoustic stimulus is delivered by a probe fitted in the ear canal.

OAEs arise as a by-product of the normal function of the OHCs and travel as reverse waves towards the middle ear (ME).

The low-level acoustical signals (OAEs) are recorded by a microphone fitted into the ear canal.

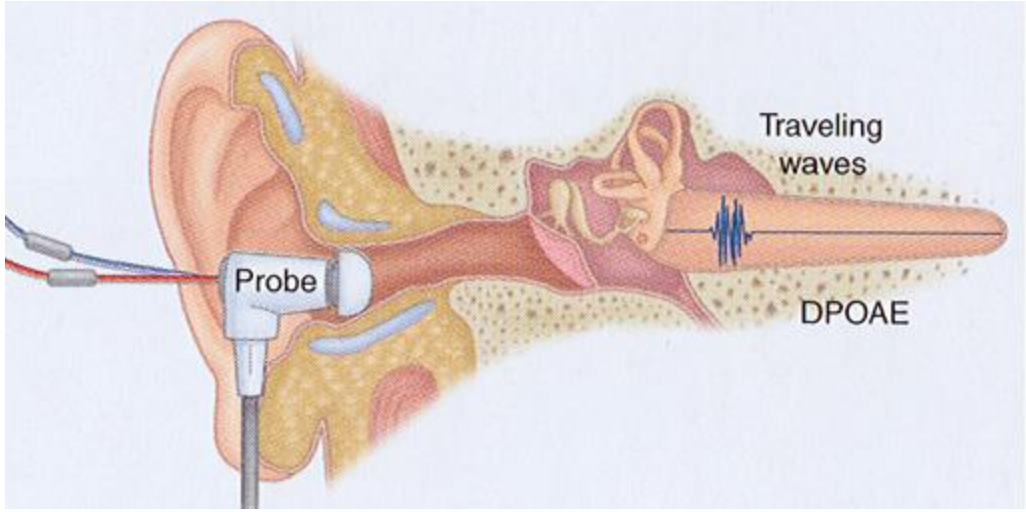
Otoacoustic Emissions

- Energy produced by the cochlea;
- Recorded (acoustically) in the ear canal;
- Provide fast, and objective means of evaluating cochlear function;
- OAEs only reflect OHC functionality under the assumption the ME function is normal.



Distortion Product OAEs (DPOAEs)

Adopted from Clark & Ohlemiller (2008)



The probe contains a microphone and two speakers.

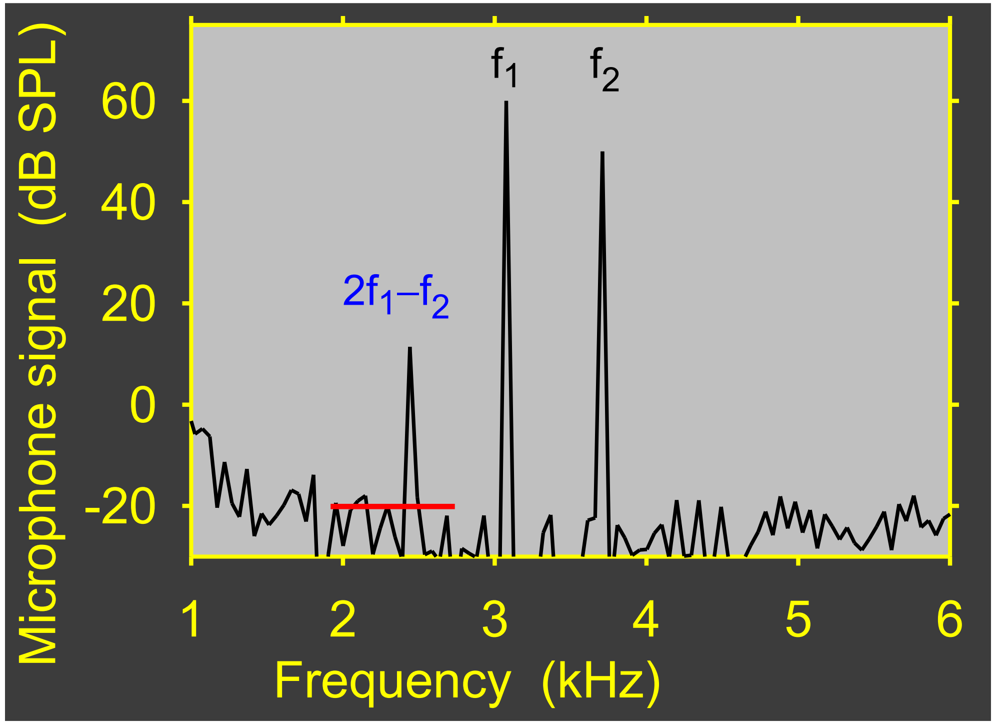
Each transducer delivers one pure tone. The signals with frequencies f_1 and f_2 (AKA primaries) are mixed in the ear canal.

The microphone records the acoustical signal in the ear canal.

Primaries ($f_1 < f_2$) are presented for at least 2 s.

The averaging and artifact rejection protocols are implemented.

Distortion product OAEs (DPOAEs)



f_1=3,100 Hz presented @ 60 dB SPL

f_2=3,700 Hz presented @ 50 dB SPL

Signal (DPOAE) @ 2,500 Hz: +12 dB SPL

Noise: -18 dB SPL around $2f_1$-f_2

Signal-to-noise ratio (S/N): 30 dB

In a patient with a normal ME function and a normal function of OHCs, the spectrum includes a component at $2f_1$-f_2 resulting from the nonlinearity of the cochlea.

The level of that signal and its separation from the noise are the results of a DPOAE test for <u>one pair of the primaries</u>.

Important aspects of DPOAE testing

Interpreting a single DPOAE data point as a valid result is based on two criteria:

- the magnitude of the DPOAE signal needs to be greater than a specified minimum, e.g., >-5 dB SPL;
- the level of the DPOAE signal needs to be above the estimation of the noise level by a specified minimum; for example, signal-to-noise ratio S/N>6 dB.

A DPOAE evaluation, known as a DP-gram, requires collecting DPOAEs for at least 4 pairs of the primaries, but typically more data points, e.g., 6 or 8, are collected. A criterion of classifying a DP-gram as an overall "pass" or "refer" needs to be specified.

Important aspects of DPOAE testing

Achieving an advisable S/N may be challenging due to:

- short-time noise artefacts, including swallowing, patient’s movements, and rubbing of the probe cable; can be handled by an effective artefact rejection approach;
- continuous ambient noise, for instance, background conversation, traffic noise, or noise created by heating/air condition systems; weighted averaging is not an effective approach.

Important aspects of DPOAE testing

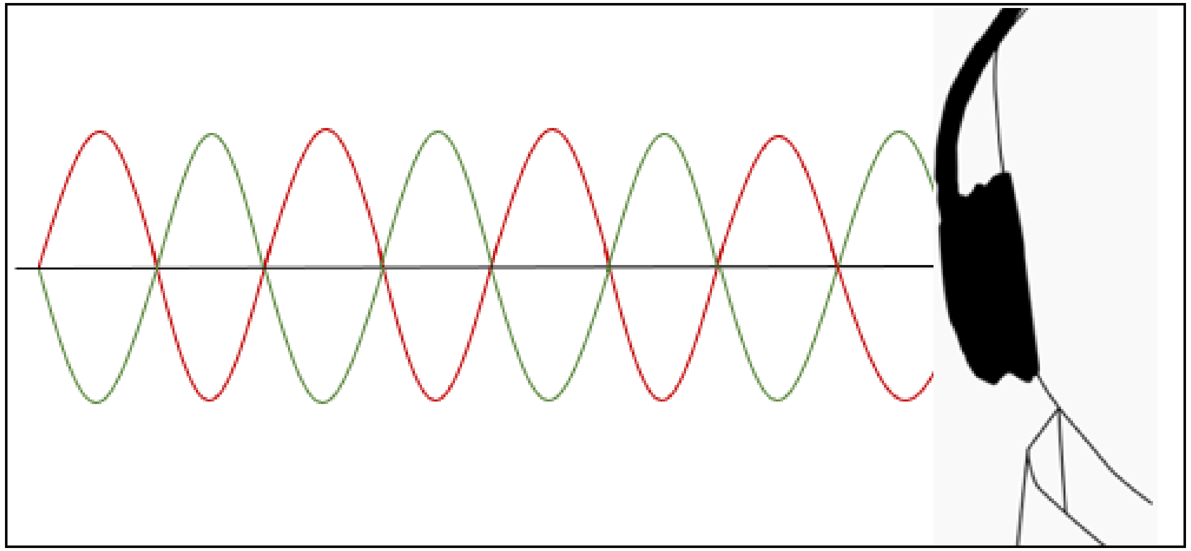
Even a good probe fit does not eliminate external sounds entering the ear canal.

Therefore, it is desirable to measure DPOAEs in a sound booth to reduce the noise floor.

For testing in an unquiet environment, e.g., in clinic offices or schools, attaining an advisable S/N may be difficult.

Applying a noise cancelling algorithm can potentially allow DPOAE testing in adverse environmental conditions.

How does noise cancellation work, for example, in audio devices?



Adopted from www.sony.co.uk

Noise-cancelling audio devices use a built-in microphone to analyze the ambient sound waves (red). The opposite sound waves (green) are generated. These two waves are added to reduce surrounding sound reaching the ear canal.

Adaptive Noise Cancelling Probe: QSCREEN system

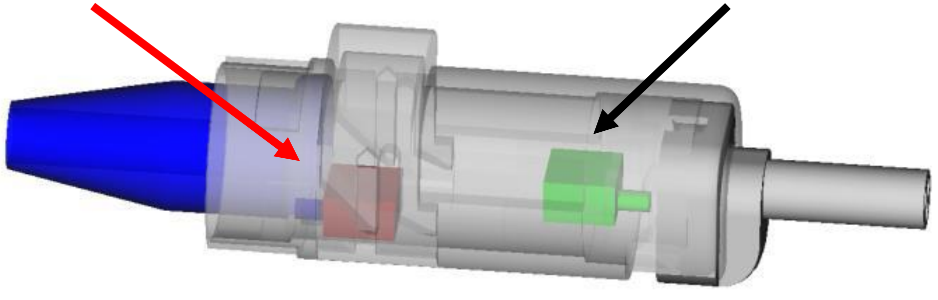
The LT-probe features two microphones:

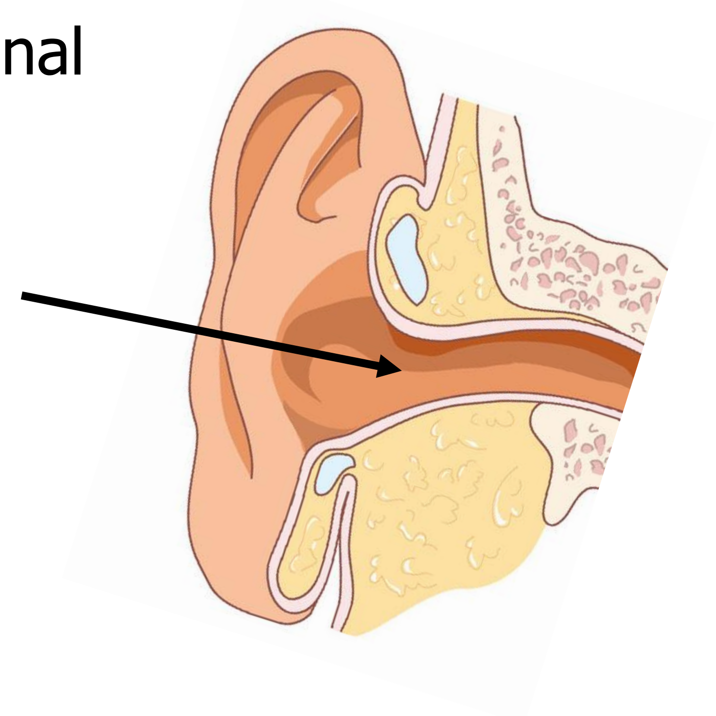
microphone 1 captures the response within the ear canal;

microphone 2 captures the environmental noise.

Mic 2: monitoring environmental noise

Mic 1: detection of DPOAE in the ear canal





Adaptive Noise Cancelling Probe: QSCREEN system

An Adaptive Noise Cancelling (ANC) algorithm is applied to produce a virtual replica of the ambient noise reaching the ear canal.

By subtracting the output from the primary microphone signal, ambient noise in the ear canal is suppressed without influencing the OAE response.

The adaptive filter follows changes of the noise and reduces test time in noisy surroundings.

Rationale for the study

The aim of the study was to collect DPOAEs with the QSCREEN system under simulated noisy environment conditions to evaluate whether applying the ANC algorithm:

1. decreases number of false positives, i.e., those cases when DPOAE results incorrectly imply abnormal cochlear function;
2. reduces testing time significantly.

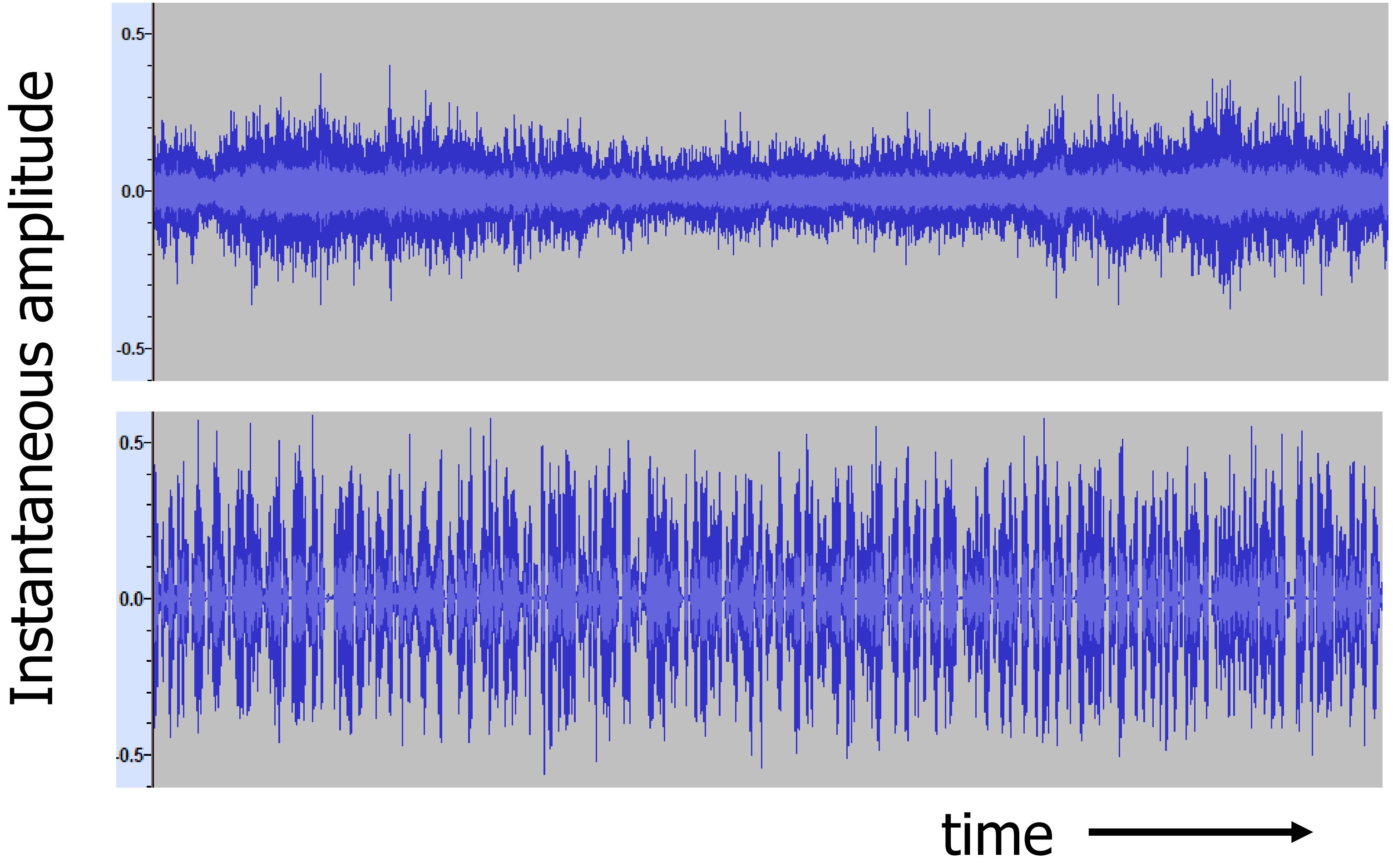
Methods

The DPOAEs were recorded in subjects seated comfortably in a reclining chair outside the audiometric booth.

The tests were performed with the ANC turned off and on under three conditions:

1. without presenting any signals from loudspeakers of an audio system (ambient noise level ≈35 dBA);
2. with a cafeteria noise presented at 60 and 70 dBA;
3. with Fastl noise presented at 50, 60, and 70 dBA.

Methods: Cafeteria vs Fastl noise



Cafeteria noise

Fastl noise

Fastl (1975)
Audiological Acoustics

The fluctuation of the envelope of Fastl noise reflects the sensitivity of the hearing system to different frequency fluctuations.

Methods

The DPOAEs were recorded in 26 ears of young adults with normal hearing, twice for each ear with a probe removed and repositioned.

The DP-gram, i.e., a set of DPOAE measurements with:

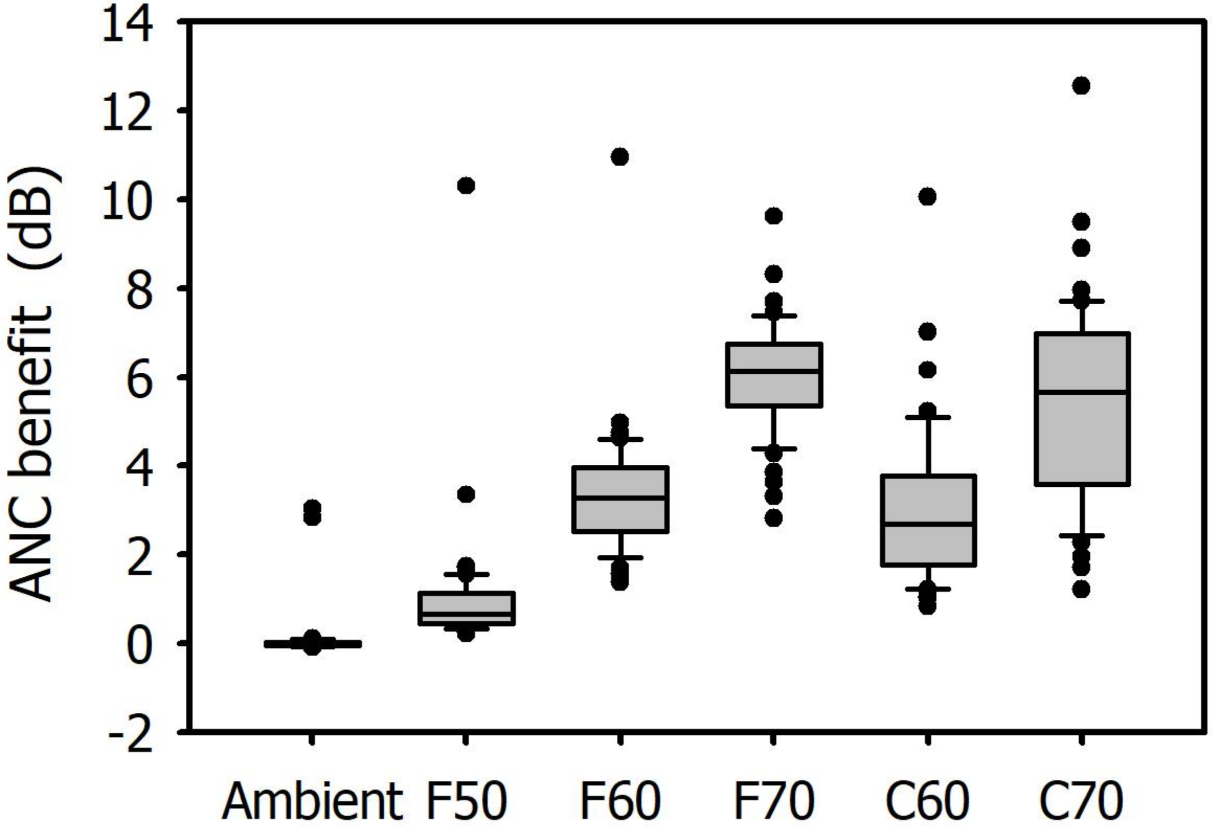
f_2 frequency of 1, 1.5, 2, 3, 4, and 6 kHz; $f_2/f_1=1.22$; $L_1=61/L_2=55$ dB SPL;

minimum recording time per a f_1 and f_2 pair set at 2.1 sec;

if S/N>9dB was not reached after the maximum averaging time of 15.2 sec, the data point was considered a "refer".

Results: the ANC benefit

The ANC benefit (in dB) represents reduction of the environmental noise reaching the ear canal. For example, the ANC of 3 dB is equivalent to saving approximately half of the recording time.



F50: Fastl noise at 50 dBA

F60: Fastl noise at 60 dBA

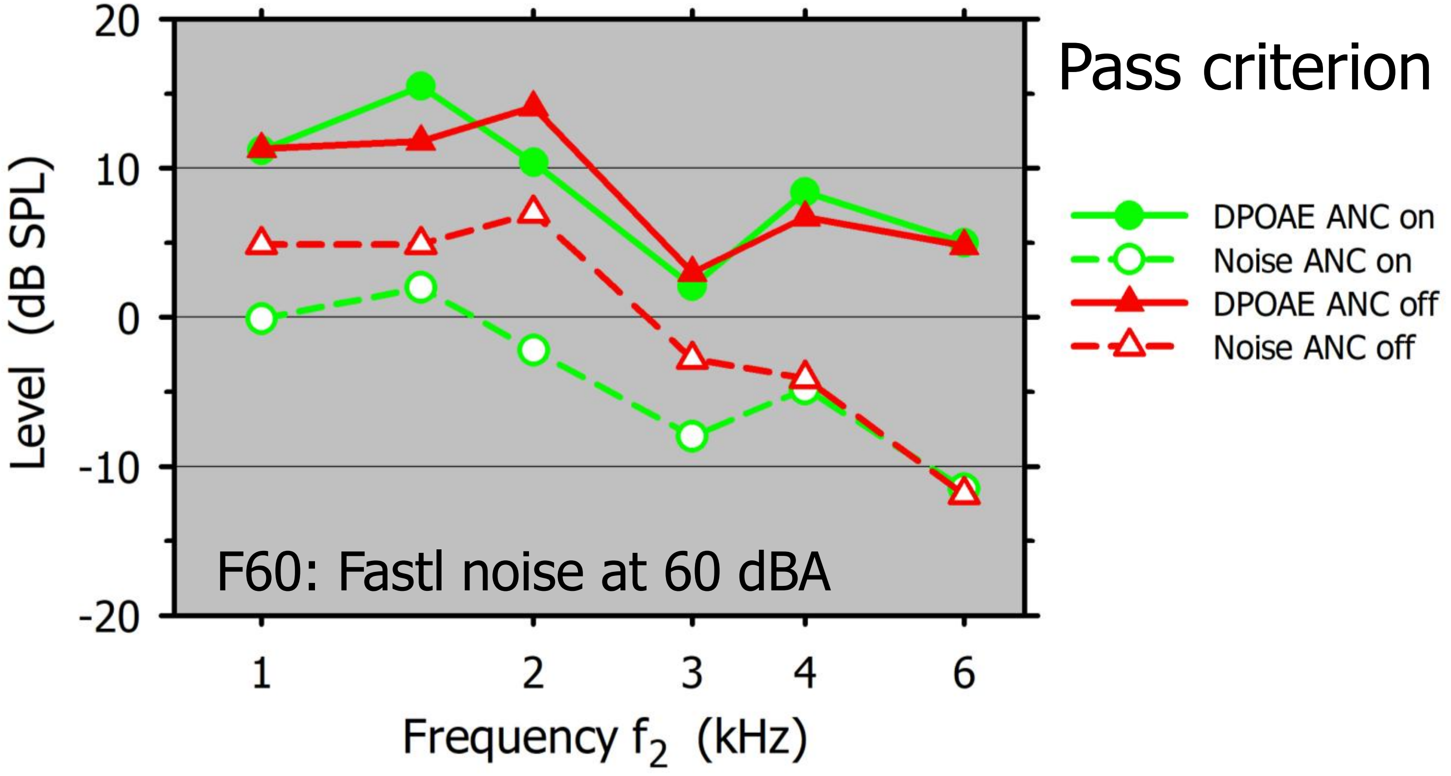
F70: Fastl noise at 70 dBA

C60: Cafeteria noise at 60 dBA

C70: Cafeteria noise at 70 dBA

The ANC benefit increased with increasing noise level for both Fastl and cafeteria noise.

An example of DP-grams with the ANC turned on and off



Pass criterion per point: S/N>9 dB

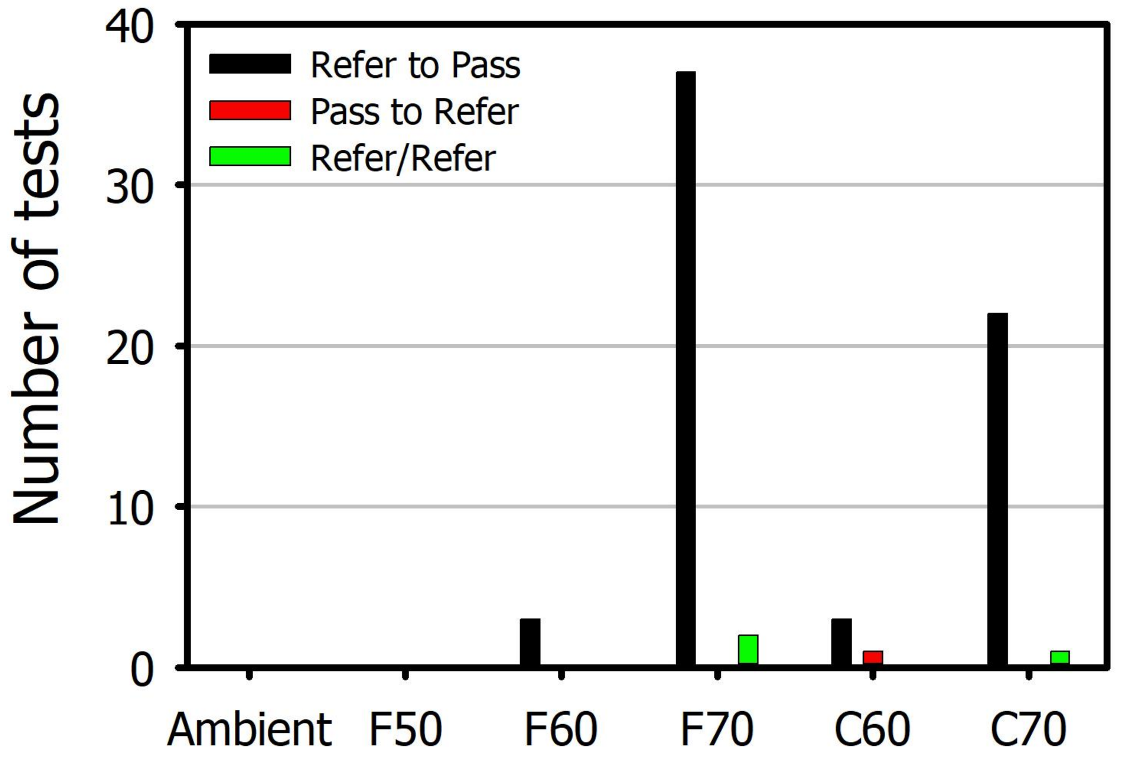
Pass at all 6 frequencies

Pass only @ f_2=4 & 6 kHz; i.e., overall "fail"

Applying the ANC resulted in a decrease of the noise level for $f_2 \leq 3$ kHz, thus converting "refer" to "pass" for f_2=1, 1.5, 2, and 3 kHz.

The overall pass criterion required at least 4 "pass" results out of 6 frequencies tested.

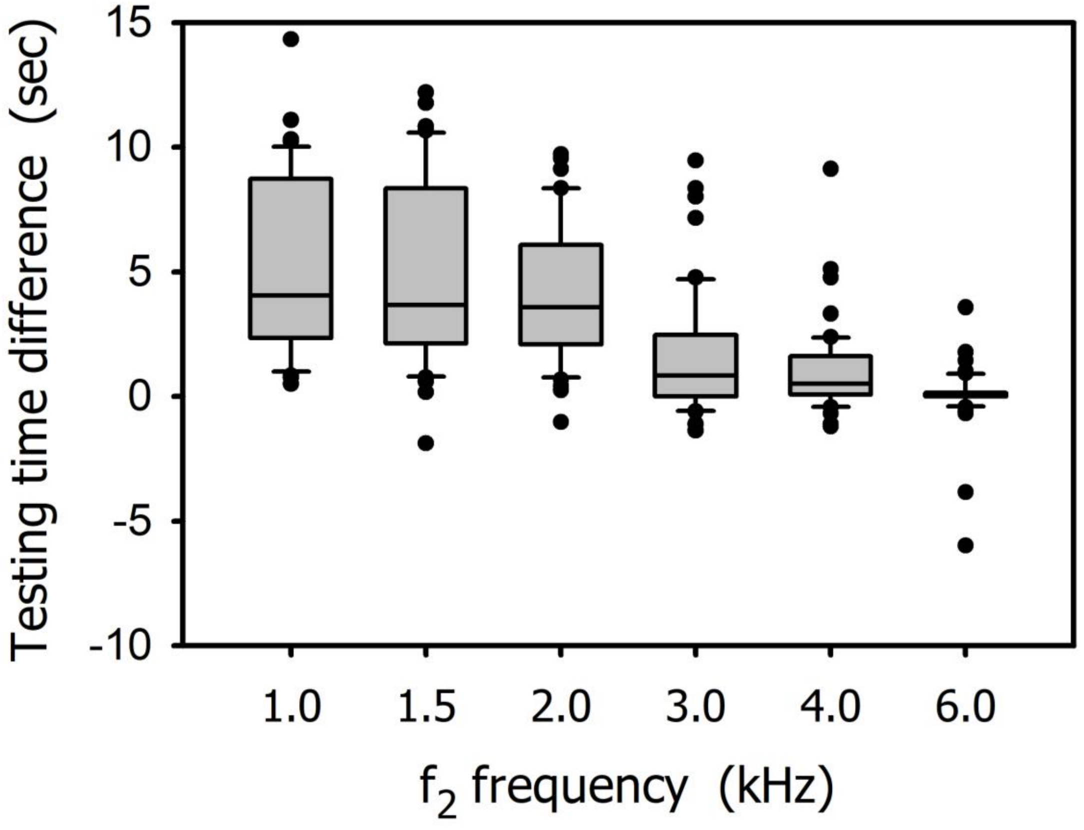
Results: change of overall "refer" to "pass" outcomes

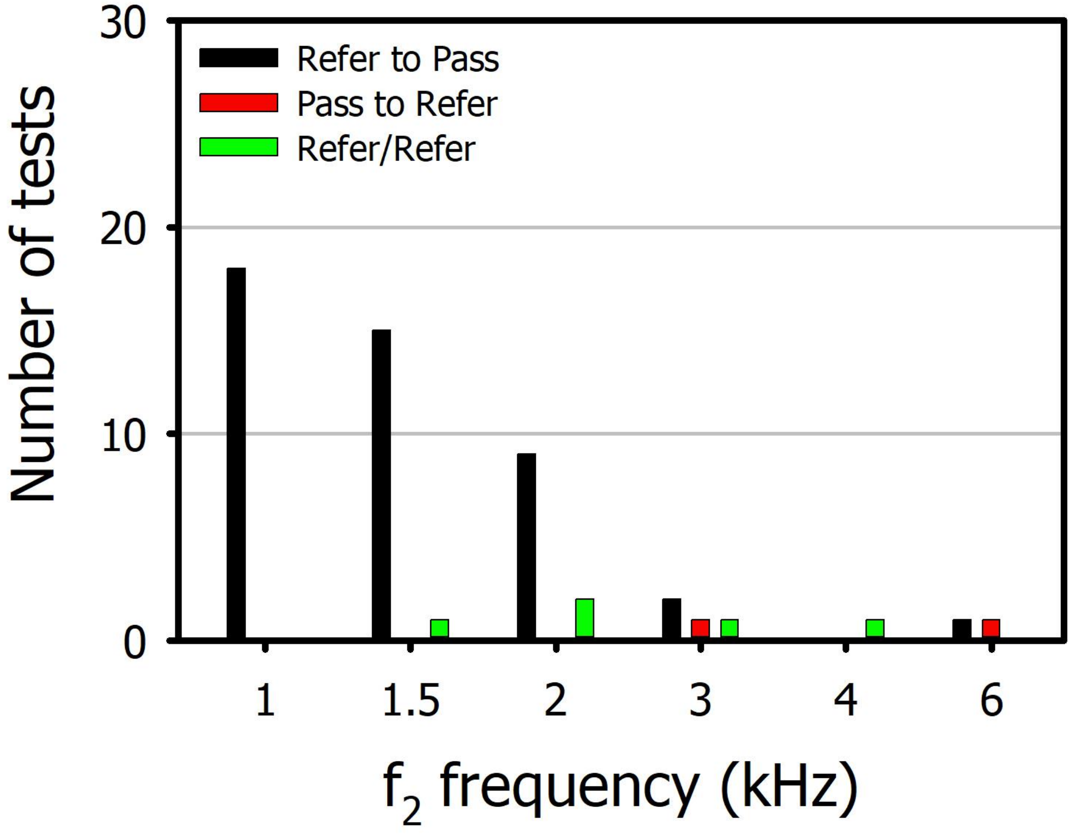


For Fastl noise presented at 70 dBA, over 70% of initial overall "refer" cases changed to "pass" results after applying the ANC.

The ANC algorithm did not have a significant influence for tests performed in the ambient noise and the F50 conditions.

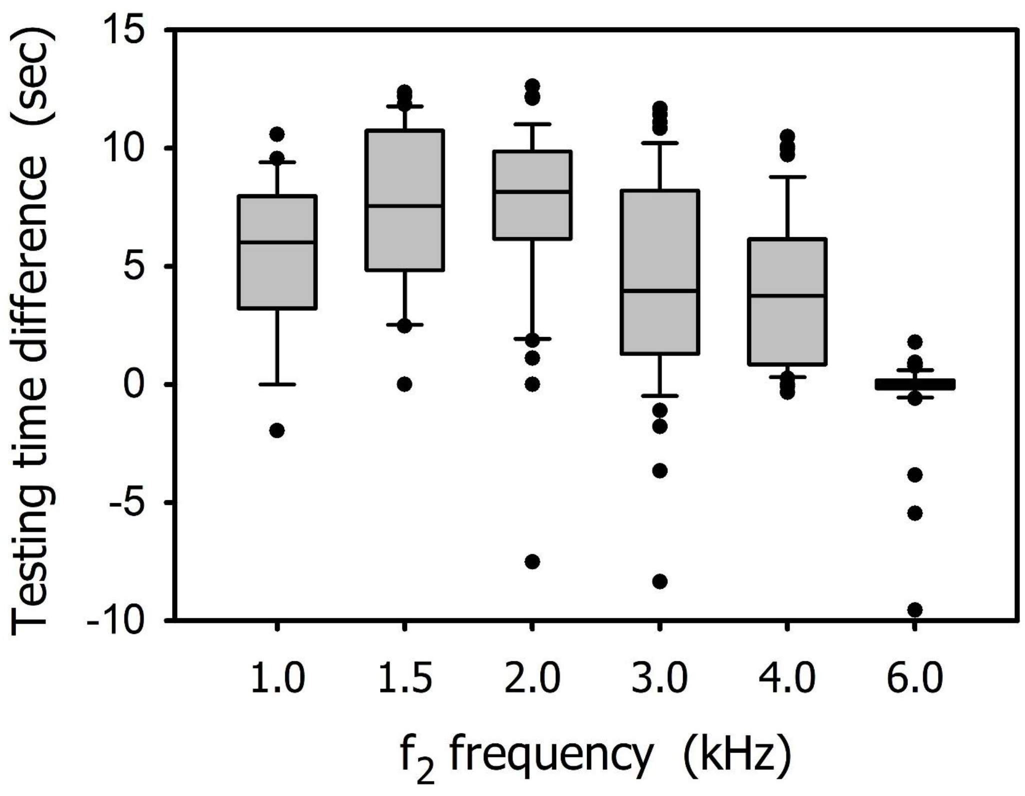
Results: Fastl noise presented at 60 dBA

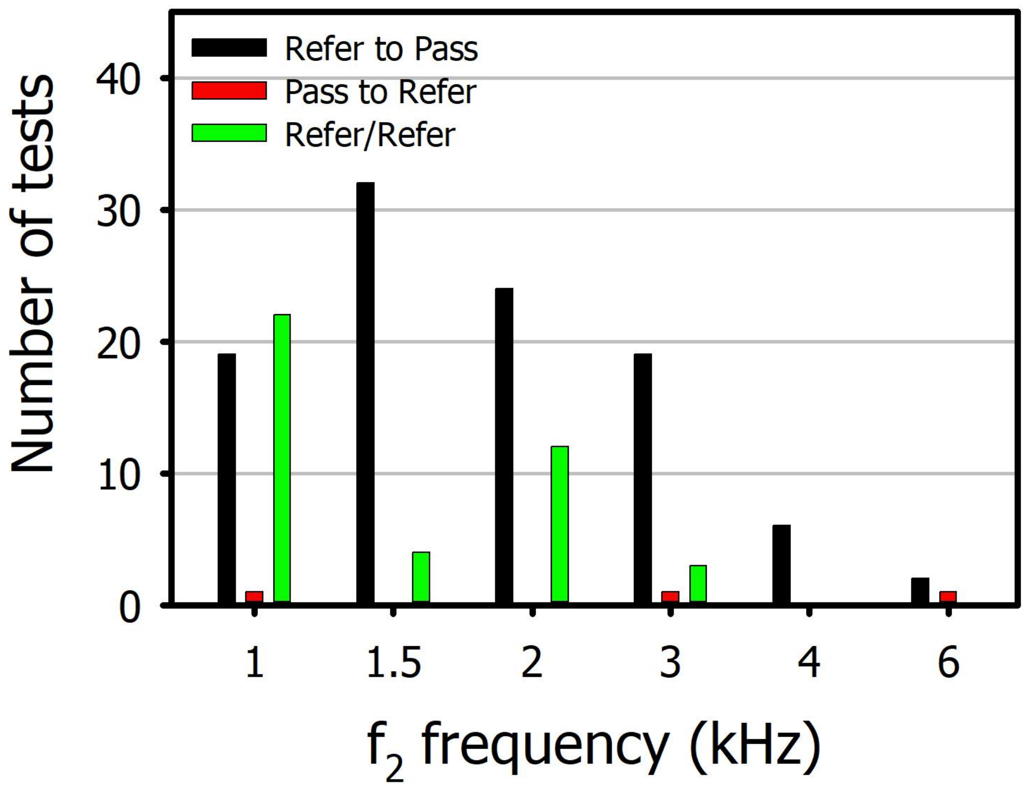




For Fastl noise presented at 60 dBA, applying the ANC was the most beneficial for $f_2 \leq 2$ kHz.

Results: Fastl noise presented at 70 dBA

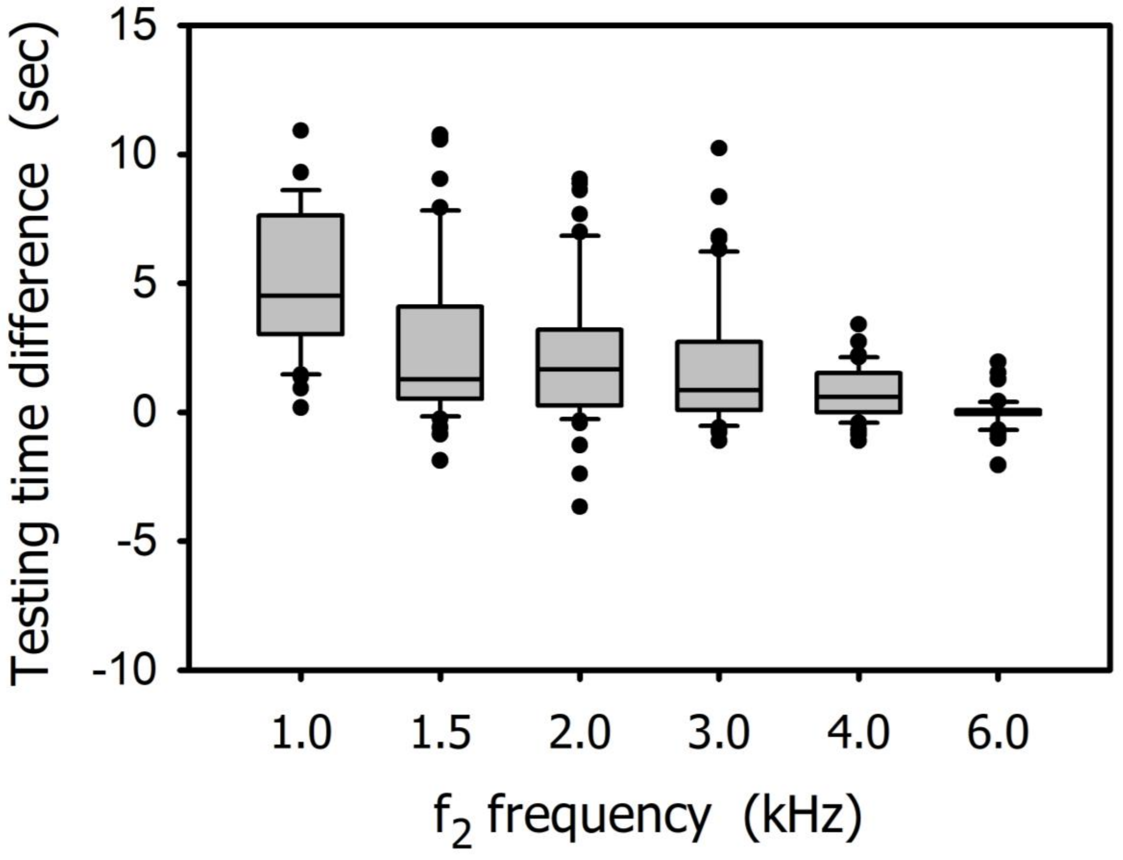


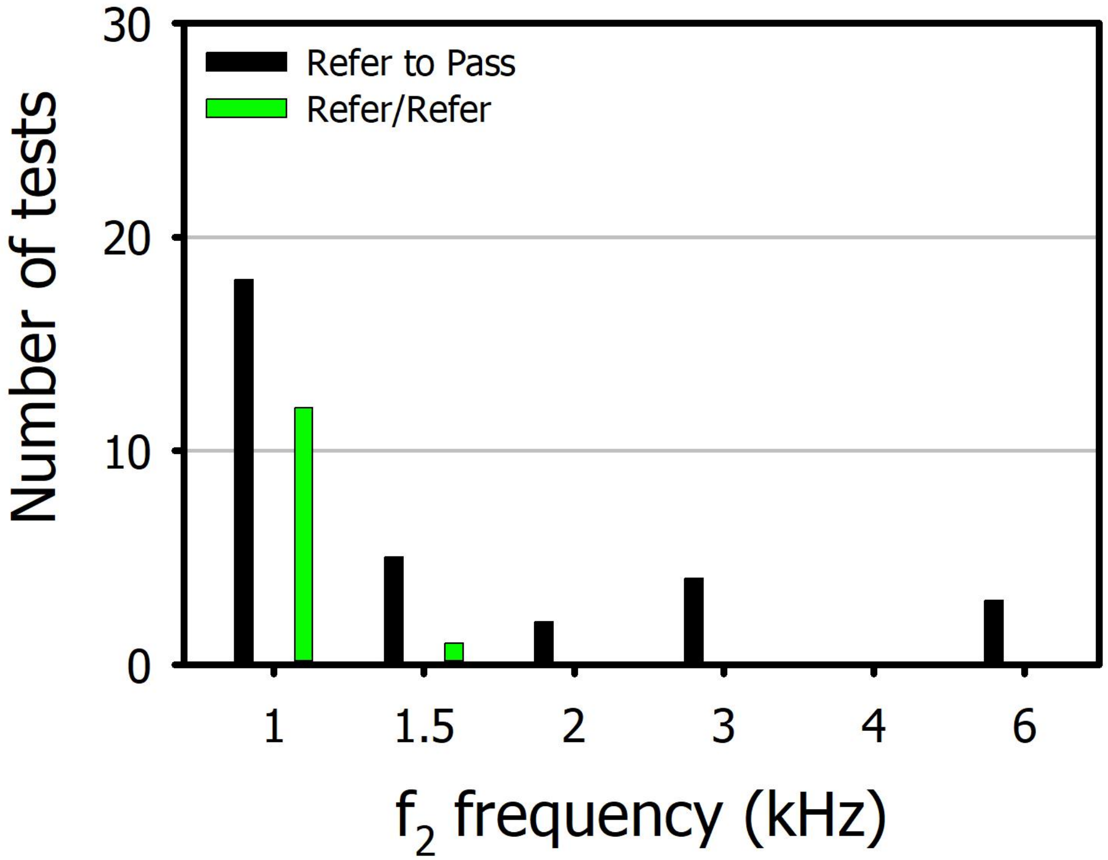


For Fastl noise presented at 70 dBA, applying the ANC reduced testing time at all frequencies, except for f_2=6 kHz.

In some ears with relatively weak DPOAEs at f_2=1 kHz, applying the ANC has not resulted in converting "refer" to "pass" outcomes.

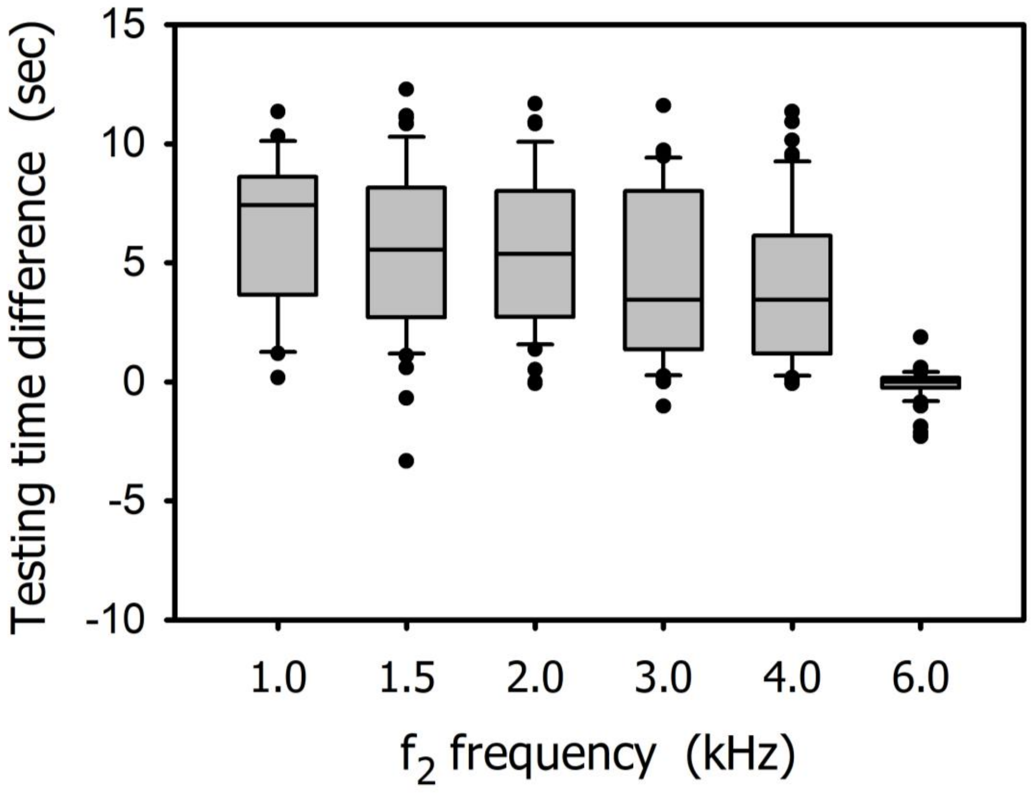
Results: cafeteria noise presented at 60 dBA

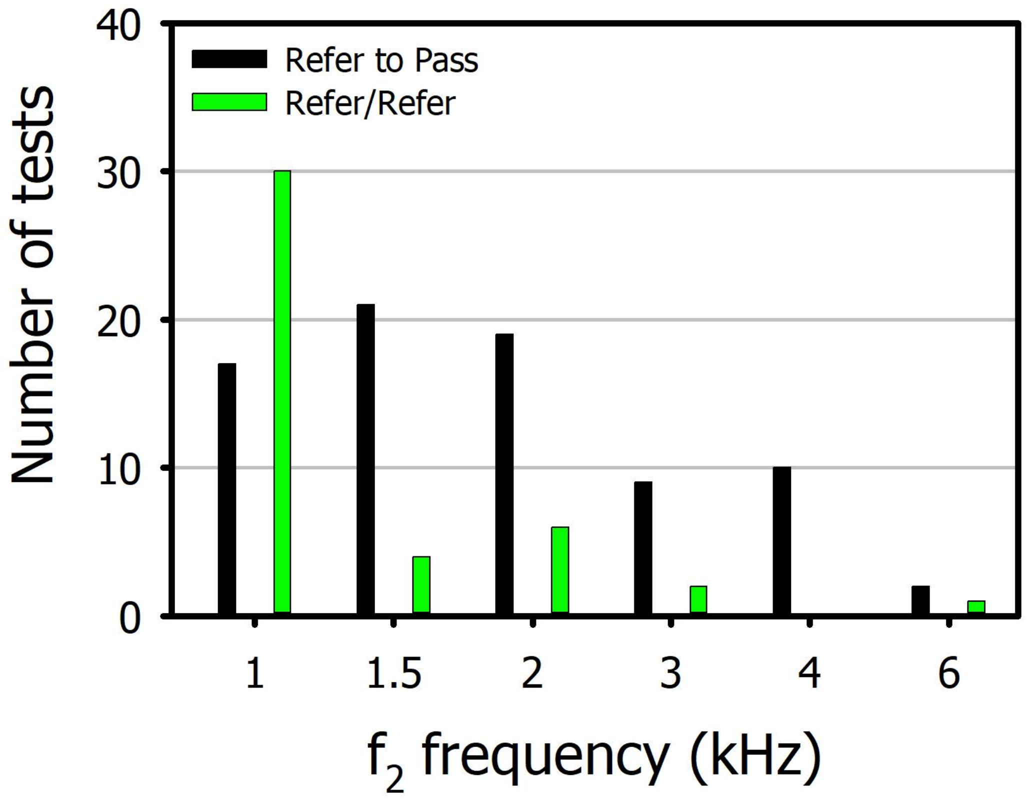




For the cafeteria noise presented at 60 dBA, applying the ANC was the most beneficial for f_2=1 kHz.

Results: cafeteria noise presented at 70 dBA





For the cafeteria noise presented at 70 dBA, applying the ANC was the most beneficial for $f_2 \leq 2$ kHz.

In some ears with relatively weak DPOAEs at $f_2 = 1$ kHz, applying the ANC has not resulted in converting "refer" to "pass" outcomes.

Conclusions

The ANC algorithm based on using the second microphone pointing outwards for capturing ambient noise resulted in a decreased impact of the environmental noise without influencing the DPOAE response.

Conclusions

The first benefit was a reduced number of false positives, i.e., an improvement of specificity.

1. Greatest change of overall results from "refer" to "pass" was for the F70 and C70 noise conditions.
2. Across conditions, the highest "refer" to "pass" change occurred for f_2=1, 1.5, and 2 kHz with the ANC turned on; this is the frequency region where spectra of air condition, traffic noise, and background conversation are expected to have the highest components.

Conclusions

The second benefit was a shorter testing time.

1. Overall test time difference was up to 45 seconds, with the median value of 35 seconds.
2. Across conditions, the test time difference was greatest for f_2=1, 1.5, and 2 kHz with the ANC turned on.

Additional pilot data collected for the cafeteria noise presented at 50 dBA did not show a significant influence of the ANC algorithm.

Conclusions

The LT-probe with the ANC algorithm should be useful for performing the screening of cochlea function based on DPOAEs collected in adverse environmental conditions, e.g., at bedside, in pediatrician offices or in schools, where the noise levels are typically lower than those of the F70 and C70 conditions applied in the current study.

Final thoughts

Before universal screening programs were implemented across the US, hearing loss was often not identified until 2.5 to 3 years of age.

Recent studies have reported the average age of diagnosis to be as young as 3.7 months (CDC, 2025).

Otoacoustic emissions tests are important components of "hearing" screening programs, including newborns, infants, and children.

Please recall that OAEs do not provide any information about the status of the auditory system above the level of OHCs. Therefore, an OAE test is not a hearing test.

Final thoughts

Recent advances in technology, for example, applying the ANC algorithm (current study), a simultaneous testing of both ears of a patient, and using two pairs of the primaries simultaneously, may result in a significant reduction of testing time.

Therefore, it is feasible to conduct the DPOAE tests efficiently not only in audiology clinics, but also in preschools and elementary schools.