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Whitepaper
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Audible Contrast Threshold (ACT™)

A language-independent diagnostic test to quantify real-life speech-in-noise ability and personalise help-in-noise settings in hearing aids

EDITORS OF ISSUE

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Abstract
Difficulty hearing in noise is a key manifestation of hearing loss. For many, hearing in noise and particularly understanding speech in noise remains an issue even when they are provided amplification via a hearing aid. Although this fact is known from more than half a century of scientific research, there is, to date, no evidence-based method to adjust advanced hearing-aid settings based on a standard clinical assessment of a person's hearing-in-noise ability. When it comes to help-in-noise features, most hearing-aid users are offered the default settings at first fit, and if adjusted, the settings are determined subjectively and often reevaluated in a trial-and-error process. This whitepaper introduces the Audible Contrast Threshold (ACT) diagnostic test, a language-independent, fast, and reliable method to assess a person's real-life speech-in-noise ability. The research background and studies that have led to the development and optimisation of the test for clinical use are described, with a summary of the main principles behind the ACT test procedure. The first large-scale clinical study with ACT and hearing-aid users is then presented. The results confirm a strong relationship between ACT and speech-in-noise ability across languages. The usefulness of ACT to guide prescription of beneficial amounts of help-in-noise in hearing aids is also demonstrated, as is the excellent reliability of the test. With ACT, it is now possible to personalise help-in-noise settings more objectively in hearing aids based on the user's measured individual need for help in noise. In a joint effort, Interacoustics and Oticon have now defined the first evidence-based prescription rule for help-in-noise settings in Oticon hearing aids. This prescription rule enables seamless integration of ACT-based personalisation in the Oticon fitting software.

Hearing in noise: The importance of looking beyond the audiogram

For more than 100 years, the only diagnostic measurement used to fit hearing aids was the pure-tone audiogram. The audiogram has served and continues to serve us well in characterizing a prospective hearing-aid user's ability to hear soft sounds – or the lack of this ability. From the audiogram, the hearing-care professional (HCP) can adequately address issues related to audibility in the hearing-aid fitting. However, every HCP knows that a hearing loss is much more than lack of audibility. In particular, hearing loss affects the ability to understand speech in the presence of background noise – even when audibility has been properly compensated for (e.g., Lopez-Poveda, 2014). This is not a new realization. Almost a half century ago Plomp (1978; 1986) suggested a model for speech understanding in noise with two independent detrimental factors to speech intelligibility: audibility and distortion. Both these factors contribute to a need for higher signal-to-noise ratio (SNR) to understand speech in noise. Other researchers found support for Plomp's two-factor model, e.g., in the sense that audibility alone (pure-tone thresholds) was able to explain only 50% of the variance in speech-in-noise performance (e.g., Smoorenburg, 1992). Here, in the context of the Audible Contrast Threshold (ACT) test, we will use the terms "audibility loss" and "contrast loss" to cover Plomp's concepts of audibility and distortion, respectively. Audibility loss is well established and is measured with the audiogram. Contrast loss is a new term, which refers to the amount of contrast a person needs between the desired speech they want to hear and the undesired background sounds. Thus, if a person has a severe contrast loss, they need a better SNR to perform similarly to a person with a mild contrast loss. Up to now, there was no standard clinical measure for contrast loss.

To compensate for hearing-in-noise problems, or contrast loss, modern hearing aids use powerful help-in-noise technology (Jensen & Pedersen, 2015; Andersen et al., 2021). This technology is highly adjustable in the fitting software and is thus, in principle, able to provide different "help levels" in noise for each user. However, there is currently no objective evidence-based way of selecting the adequate help level for the individual. Therefore, the help-in-noise features are often left in their moderate default settings. This represents missed opportunities, particularly for those hearing-aid users who really struggle with hearing in noise and who would benefit greatly from the strongest settings available. Similar opportunities exist at the other end of the spectrum, in users with near-normal speech-in-noise ability (once audibility has been taken care of). Such users might be better off with a mild setting of the help-in-noise features to give them a less processed sound scene also in situations that most other hearing-aid users would find challenging. Thus, an objective diagnostic test that could inform the HCP about the individual's aided speech-in-noise abilities up front would be very useful. Besides the potential prescriptive benefits mentioned above, such a prediction of speech-in-noise ability would also be useful for counselling, setting expectations for the outcome with hearing aids, and for recommending additional help such as assistive listening devices, communication strategies, and auditory training. Again, this is not a new idea. For several decades researchers have been looking for such a diagnostic test, but until recently with very limited success (e.g., Strelcyk & Dau, 2009; Johannesen et al., 2014; Thorup et al., 2016). This began to change in the early 2010s when research articles were published showing as yet unseen high correlations between measures of speech-in-noise performance and so-called spectro-temporal modulation (STM) detection thresholds (Bernstein et al., 2013; Mehraei et al., 2014) in participants with hearing loss.

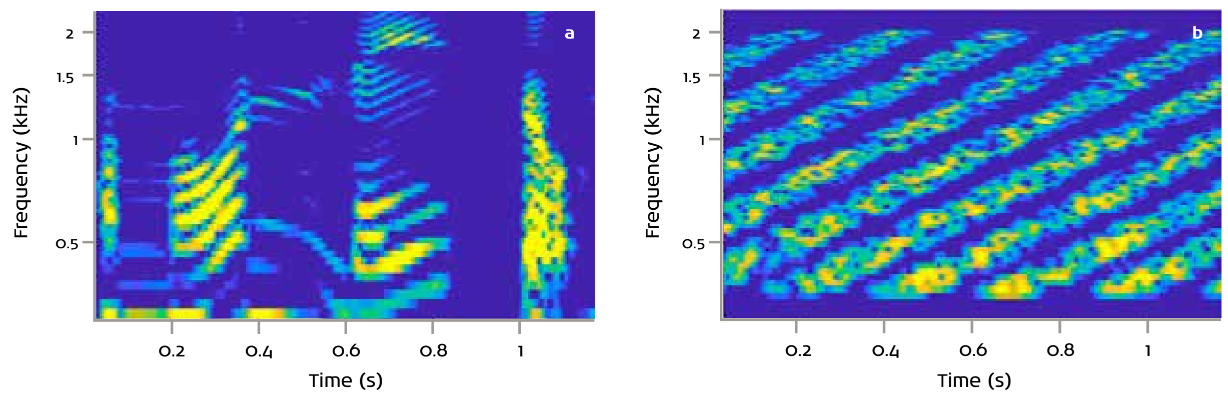

Figure 1: Spectrograms of (a) a single Danish sentence from the Hearing In Noise Test (HINT, Nielsen & Dau, 2011), and (b) an STM/ACT stimulus with maximal spectro-temporal modulation imposed.

Spectro-temporal modulations are intrinsic to speech signals, and the modulations used for STM testing are like those found in speech, albeit in a stylized fashion. See examples of real speech and STM stimulus spectrograms in Figure 1.

An STM detection threshold (and eventually an Audible Contrast Threshold, or ACT) is experimentally found by adaptively varying the degree of modulation in the stimulus, which is delivered through headphones or insert earphones. The person under test is asked to respond to "target" stimuli with modulations while comparing these to unmodulated "reference" stimuli. The threshold is then the smallest degree of modulation that the person can detect. The general thinking is that if a person is good at the ACT test (or equivalently STM detection), then they will also be good at picking out speech from background noise even when there is very little contrast between speech and background noise. Vice versa, a person with poor ACT/STM will need a larger contrast between speech and background noise to understand the speech. Using ACT/STM to estimate speech-in-noise ability has the further advantage that the testing is not using language-specific speech material but relies on artificial stimuli. In this way, ACT/STM can be used with anyone in any country irrespective of language background.

Despite encouraging results from Bernstein et al. (2013) and Mehraei et al. (2014), there were still challenges observed. When the STM test from Bernstein et al. (2013) was deployed in a large clinical study in Sweden (Bernstein et al., 2016) about one third of the participants tested were unable to obtain proper STM thresholds from the adaptive test procedure.

Based on this mixture of very promising results and considerable barriers to clinical use, Interacoustics and Oticon decided to embark on a research journey together. The goals were to mature the STM test to unleash its full potential, and ultimately translate it into a viable clinical tool: the Audible Contrast Threshold (ACT) test.

Development of the ACT test:
A scientific journey

This section describes a succession of research studies carried out at the Interacoustics Research Unit in collaboration with the Technical University of Denmark (DTU). The starting point was the STM test proposed by Bernstein et al. (2013; 2016) and the end point the clinical ACT test.

The first study (Zaar et al., 2023a) had the primary goal of solving the 'ceiling issue' from Bernstein et al. (2016) to allow all participants to obtain a proper threshold from the test. To achieve this, several modifications to the test procedure were introduced:

- The test paradigm was changed from a 2-Alternative Forced Choice (2-AFC) to a 3-AFC paradigm. In 2-AFC, the task of the participant is to identify the modulated stimulus in a random-order pair of an unmodulated reference stimulus and a modulated target stimulus. In this way, the participant needs to memorise what the modulated target sounds like. In 3-AFC, the task is to identify the oddball in a triplet of stimuli with two references and one randomly placed target. In that way, no specific concept of the target sound needs to be established, which makes for an easier task.

- Each stimulus presentation was extended from 0.5 to 1 second. Allowing more time for detecting the modulations makes the task easier.

- Instead of monaural stimulus presentation as in Bernstein et al. (2013; 2016), stimuli were presented bilaterally. This modification was mainly introduced to improve the correspondence with real-world listening to speech-in-noise scenarios, where both ears are typically used. The modification also contributes to making detection easier.

- Finally, frequency-specific shaping of the test stimuli was introduced, based on the "sufficiently audible" strategy proposed by Humes (2007). This procedure takes the individual audiogram into account and ensures that there is at least 15 dB of audibility throughout the frequency range of stimulation, see Figure 2 for an illustration. Besides guaranteeing full audibility, the procedure also approximates the amplification that hearing aids would provide for speech-in-noise scenarios. The sufficiently audible approach contrasts with that taken by Bernstein et al. (2013; 2016), where the stimuli were played at a fixed loud level without frequency-shaping. Bernstein's approach neither guarantees full audibility nor does it correspond to how hearing aids would amplify speech-in-noise scenarios.

In addition to assessing the mentioned changes introduced to the test paradigm, several flavours of STM were examined in the study. These include variants based on a tone-complex carrier signal as an alternative to the band-limited stationary pink-noise carrier used up to then. Thirteen test participants with hearing loss were recruited for the study and were tested on the different variants of STM, as well as two variants of laboratory-grade speech-in-noise tests. Specifically, a so-called "ecologically valid" (Keidser et al., 2020) speech-in-noise set-up was trialled. There, everyday sentences from the Danish Hearing In Noise Test (HINT, Nielsen & Dau, 2011) were presented against a background of competing talkers presented from separate loudspeakers together with low-level speech-shaped noise (see Figure 6 below). In addition, the loudspeakers were set up in a room with moderate reverberation. Collectively this created a more realisitic listening scenario compared with a more standard set-up where target speech is presented against steady-state noise, both from the same loudspeaker (co-located). The latter set-up that was also tested for comparison. In both conditions, audibility was ensured in a fashion like that described in Figure 2, with individualised amplification provided to the loudspeaker signals. Thus, the test participants were listening with open ears in the speech-in-noise tests. The results of the study can be summarized as follows:

- All test participants produced proper STM detection thresholds in all conditions tested, indicating that the ceiling issue from Bernstein et al. (2016) was successfully solved.

- Correlations between STM thresholds and speech reception thresholds in noise (SRTn) from the two variants of speech-in-noise testing were invariably higher for the ecologically valid condition than for the co-located standard condition. Thus, by taking a big step towards more realistic speech-in-noise testing, the relationship between STM and aided speech-in-noise performance was strengthened. Note that throughout this whitepaper, the abbreviation SRTn refers to speech reception thresholds in noise, that is, the SNR required to correctly repeat 50% of the presented sentences.

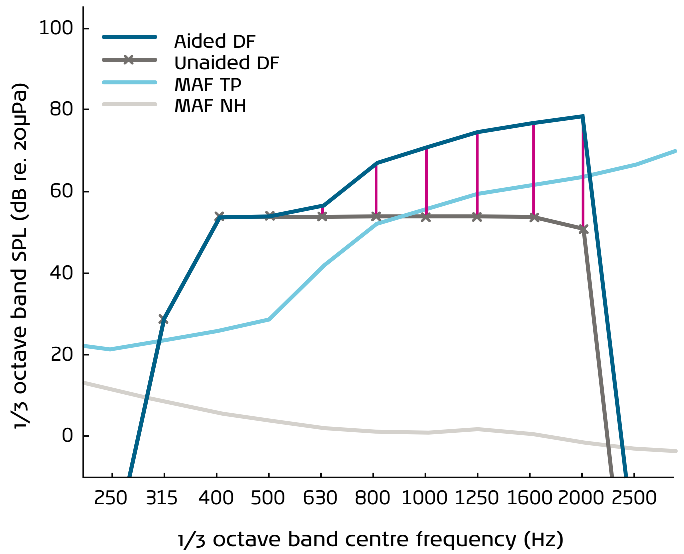

Figure 2: Illustration of the scheme used for ensuring full audibility of ACT stimuli for each individual. The dark grey line shows the spectrum of the ACT stimuli in 1/3-octave band Sound Pressure Level (SPL), as they would be presented to a normal-hearing participant (in a diffuse field (DF), albeit stimuli are in fact delivered through headphones). The light grey line shows the diffuse-field hearing threshold (minimum audible field, MAF, ISO389-7) for normal hearing, indicating excellent audibility of the unaided ACT stimuli. The light blue line indicates the hearing threshold for a representative hearing-impaired test participant (TP), leaving part of the unaided ACT stimuli below threshold for this person. The vertical magenta lines indicate gain added at 1/3-octave band centre frequencies to ensure 15 dB of audibility throughout the frequency range of the ACT stimuli. The dark blue line finally shows the spectrum of the "sufficiently audible" ACT stimuli (aided DF).

- The relationship between STM and aided speech-in-noise performance was intact after introducing several modifications to the STM test procedure.

The two most promising STM-test candidates from the first study were then tested in a new group of 30 hearing-aid users, who also underwent speech-in-noise testing with the ecologically valid set-up (Zaar et al., 2023b). Relative to the first study, the audibility compensation for the STM test was changed to consider each ear individually (the compensation in Zaar et al. (2023a) was based on a left-right average audiogram). For the speech-in-noise testing, audibility compensation was handled by bilaterally fitted Oticon Opn hearing aids with prescribed settings according to Oticon's proprietary fitting rationale, VAC+ (Le Goff, 2015). Speech testing was conducted with three settings of the hearing aid's help-in-noise feature, OpenSound Navigator (OSN): Off (OSN inactive), Medium (default OSN setting), and Strong (customized strong OSN setting). The participants for this study were specifically recruited to span an extended range of speech-in-noise ability. Emphasis was given to recruiting participants with severe speech-in-noise challenges, to acid-test our solution to the ceiling issue from the first study. In summary, the results were:

- The preferred STM stimulus configuration in terms of better test-retest reliability was that based on a 354-2000 Hz noise carrier and modulation parameters of 2 cycles per octave spectral ripple and 4 Hz temporal modulation. This is the same configuration used by Bernstein et al. (2016).

- The SRTns in the Off condition from the ecologically valid aided speech-in-noise test were well predicted by STM thresholds with $R^2 = 0.61$, while the 4-frequency better-ear pure-tone average (PTA) yielded $R^2 = 0.51$. STM and PTA provided complementary predictive power, evidenced by $R^2 = 0.69$ for a two-predictor regression model. Thus, the relationship between STM and aided speech-in-noise performance was equally robust in this extended group of test participants.

- The benefit in SRTn between the Mild and Strong OSN settings was well predicted by both STM ($R^2 = 0.51$) and PTA ($R^2 = 0.54$); the two again providing complementary information ($R^2 = 0.64$ in a combined model). This result provided the first evidence to suggest how STM (and thereby ACT) could be used to prescribe help-in-noise settings. This will be further explored below.

Final clinical implementation of ACT

In the last leg of the research journey, the STM test paradigm described above was translated into a clinically viable tool: the Audible Contrast Threshold (ACT) test (Zaar/Simonsen et al., 2023). The guiding principle was to create a procedure for ACT which would be as close as possible to that of the pure-tone audiogram, to make ACT easy to adopt for HCPs. More specifically, the requirements were (i) to shorten the test time to something clinically acceptable , (ii) to make use of only the equipment already available in a typical clinic (headphones/insert earphones and response button), and (iii) to maintain the obtained advantages of the research version.

In the preferred test paradigm, a train of 1-second stimulus "waves" is presented to the test participant, with modulated target waves appearing between unmodulated reference waves, when activated by the HCP. See Figure 3.

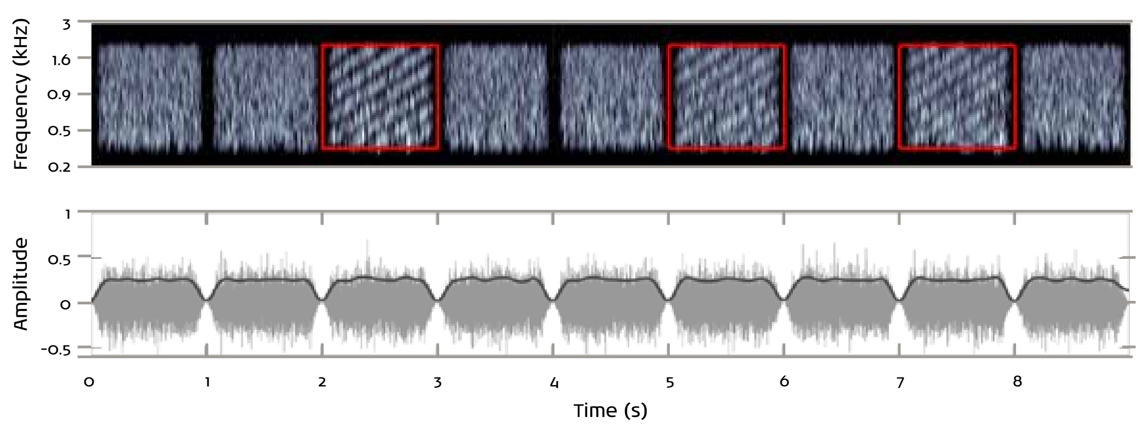

Figure 3: Illustration of the waves test paradigm used with ACT, with spectrogram (top) and waveform (bottom). The modulated target waves are indicated with red boxes in the spectrogram.

The degree of modulation is varied adaptively according to a 2-down 1-up Hughson-Westlake rule with a 2-dB step size. The measurement terminates when 3 out of 5 ascending turning points are obtained at the same modulation level; an example test run is shown in Figure 4a. In a subsequent step, the data points inside the Hughson-Westlake Threshold Candidate Window (TCW, indicated in Figure 4a) are used to estimate a psychometric function from which the final threshold is determined (Figure 4b); see (Zaar/Simonsen et al., 2023) for details. This test paradigm was found to be superior to its investigated competitors in terms of test-retest reliability. In addition, best agreement was found with the baseline results obtained in the previous study with the research version of the test.

To further align ACT with the pure-tone audiogram, a novel scale of evaluation was introduced: the normalised Contrast Level scale (which is already applied in Figure 4). To this end, 25 young test participants with normal hearing were recruited and their modulation thresholds were determined with the waves paradigm described above. The results were first registered on a technical modulation level scale, where 0 dB Full Scale (FS) corresponds to maximal possible modulation. These results are shown in Figure 5, together with the proposed normalised Contrast Level (nCL) scale. The new scale is aligned with the data such that the median performance is close to 0 dB nCL, while aligning the 2-dB test grid to include maximal modulation at 0 dB FS. In this way, 0 dB nCL corresponds to normal performance, while positive dB nCL values indicate some degree of contrast loss and negative dB nCL values indicate better-than-normal performance. Also, in alignment with the audiogram procedure, where testing is capped at -10 dB HL, the normalised Contrast Level is not adapted beyond -4 dB nCL, two steps below 0 dB nCL. In this way, the Contrast Level (dB nCL) scale used for ACT quantifies contrast loss in the same way as the Hearing Level (dB HL) scale quantifies audibility loss.

To summarize, the ACT test was developed as a clinically viable tool that allows the HCP to estimate an individual's prospective speech-in-noise performance quickly, conveniently, and accurately, in conditions where audibility has been adequately addressed with hearing-aid

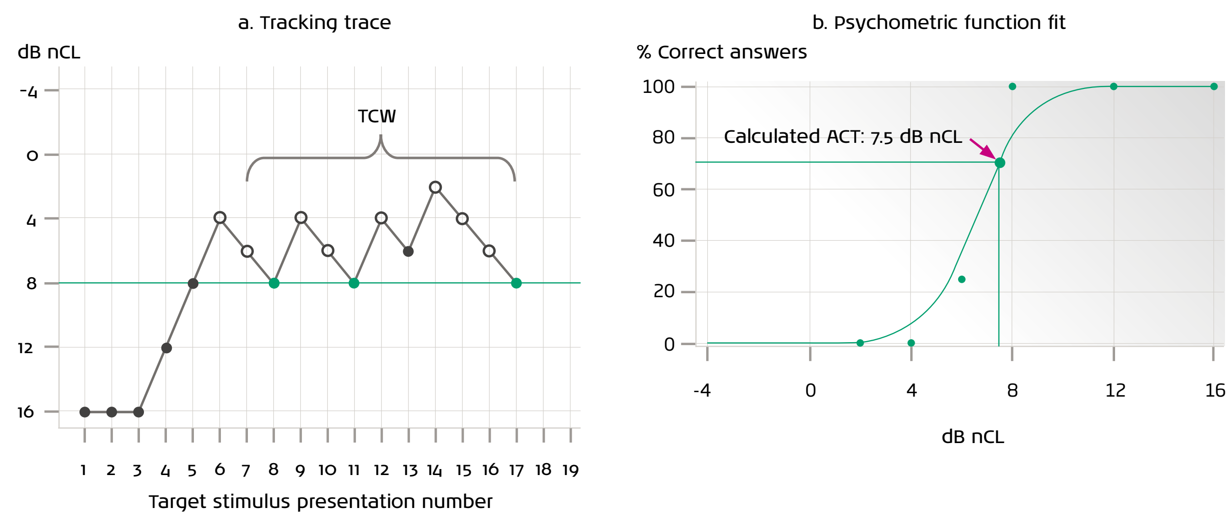

Figure 4: (a) Example "Tracking Trace" of an ACT run. A filled symbol indicates a target stimulus presentation correctly detected by the test participant, an open symbol indicates a target that was not detected, and the green check-mark symbols indicate the 3 equal ascending turning points fulfilling the Hughson-Westlake criterion. In addition, the Threshold Candidate Window (TCW) is indicated. (b) Psychometric function fit to the data in the TCW from (a). The final ACT result is determined as the 72%-point on the psychometric curve, as indicated by the straight lines.

amplification. Notably, ACT can be conveniently measured right after the audiogram – when the test participant is already wearing headphones or insert earphones and has the response button in hand. Thus, this information is available very early in the fitting process and for the first time ever, the HCP can directly address hearing-aid users' number-one complaint: hearing in noise (Jorgensen & Novak, 2020; Manchaiah et al., 2021). Moreover, this can be based on a diagnostic measure with a solid evidence base: ACT. As noted above, ACT is useful for counselling, setting expectations for hearing-aid outcomes, and for recommending additional help in terms of assistive listening devices, communication strategies, and auditory training. However, potentially the most powerful use of ACT is to prescribe settings of the hearing aid's advanced help-in-noise features, as will be explored below. Finally, it is worth re-iterating that ACT is a non-language specific test that allows everybody to be tested anywhere, irrespective of language background.

Putting ACT to the test:
A dual-site clinical study

Once the ACT test stimulus and procedure were optimized for clinical use, the next step was to confirm its applicability to real clinical populations of hearing-aid users. In a first international dual-site clinical study, independent researchers from Germany (University of Applied Sciences, Lübeck) and Japan (General Incorporated Association Shinden-Ogawa Audiology and Hearing Aid Laboratory, OTO Clinic Tokyo, and Keio University School of Medicine, Tokyo; Saiseikai Utsunomiya Hospital, Ustunomiya) measured ACT values and speech-in-noise performance in diverse populations of hearing-aid users. For more details about the study, see Zaar et al. (2023c). The study addressed the following research questions:

1. The primary research question was whether, in two real-life user groups going through different clinical flows and fitting procedures and with two very different native languages, the relationship between ACT values and speech understanding in noise observed in the earlier, more academic studies described above still held.

2. In addition, the study investigated whether ACT could increase the prediction of speech-in-noise ability substantially compared to using the audiogram alone.

Study participants

In the first part of the study, 100 experienced hearing-aid users with mild to severe hearing loss (bilateral 4-frequency pure-tone-average range: 29 to 79 dB HL, median: 51 dB HL, mean: 52 dB HL) aged 32 to 79 (median: 68 years, mean: 66 years) underwent a standard hearing-aid fitting with Oticon More 1 hearing aids. The fitting procedures for gain and choice of acoustic coupling followed the most common practice at each of the two clinical sites. The 81 German participants were fitted with the NAL-NL2 gain rationale (Keidser et al., 2011) and amplification was verified using real-ear measurements (REM). Their ear acoustic coupling was chosen as prescribed by the Genie 2 fitting software. The 19 Japanese participants underwent the Utsunomiya method of hearing rehabilitation for gain adjustment (Yamada et al., 2020) and were fitted following the guidelines defined by the Japan Audiological Society (Kodera et al., 2016). Following local practice, they all received non-vented custom ear moulds, and REM were used to assess amplification.

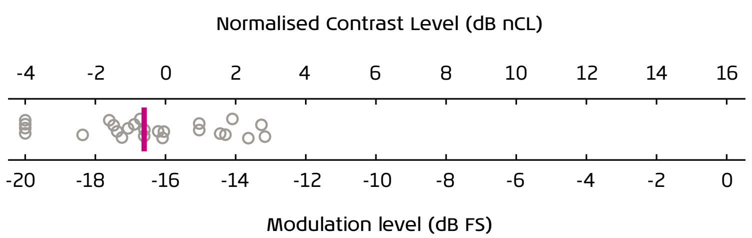

Figure 5: Results from the normative study with 25 young normally hearing test participants, shown on the technical modulation level (dB FS) axis (bottom) and the proposed normalised Contrast Level (dB nCL) axis (top). Grey circles represent individual data, while the bold vertical line indicates the median modulation level.

Test procedures

After a standard audiometric assessment, all participants performed the ACT test twice to assess its test-retest reliability. ACT was also performed twice again approximately six months later to assess the across-visit test-retest reliability. After hearing-aid fitting, the participants' speech understanding in noise was assessed while they wore the hearing aids, using an ecologically valid version of the Hearing in Noise Test (HINT, Nilsson et al., 1994). Here, the German (Joiko et al., 2021) and Japanese (Shiroma et al., 2008) corpora of the HINT were used. To make the test set-up closer to a real-life listening situation than traditional speech-in-noise tests (see Figure 6), spatially separated maskers were placed at 100° and 260° around the participant and each masker consisted of a country-specific interfering talker mixed with stationary speech-shaped noise (SSN). The target HINT sentences were presented from the front at 0°. Speech reception thresholds in noise (SRTns) corresponding to 50% sentence intelligibility were tracked for four different settings of Oticon's latest generation advanced help-in-noise feature, MoreSound IntelligenceTM (MSI). The different MSI help levels in noise are referred to as Off, Low, Moderate, and High.

To verify that the tested MSI help levels indeed provided different amounts of SNR enhancement, technical measurements were carried out in the ecologically valid HINT set-up shown in Figure 6, using a head-and-torso simulator wearing Oticon More 1 hearing aids. The broadband Speech-Intelligibility-Index-weighted output SNR was calculated using the Hagerman and Olofsson (2004) phase inversion method. The results, shown in Figure 7, confirmed that the overall SNR enhancement increased with increasing help level. Note that, for all help levels, the SNR enhancement provided by MSI depends on the input SNR. This means that MSI adapts the degree of processing it applies to the complexity of the sound scene at hand, such that more SNR enhancement is progressively applied as the sound scene becomes more complex (i.e., towards lower input SNRs in Figure 6).

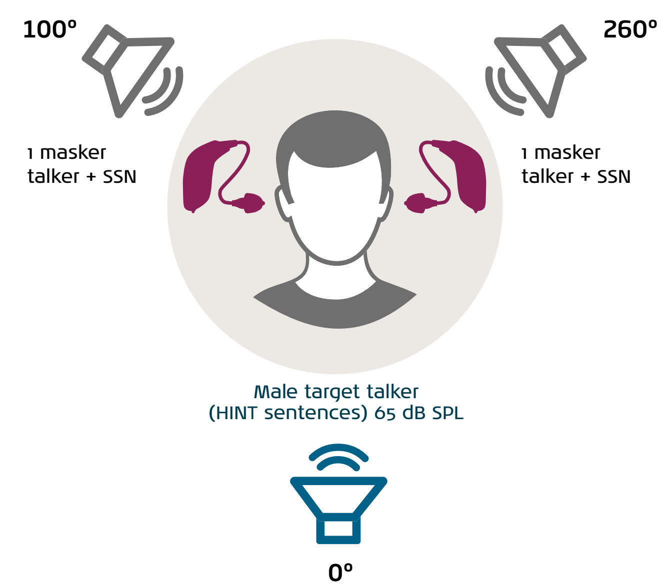

Figure 6: Ecologically valid HINT set-up to measure speech understanding in noise, with a target talker from the front and interfering talkers mixed with speech-shaped noise (SSN) from the sides.

Results: Relationship between ACT and speech understanding in noise

Our primary research question was whether the significant relationship between ACT values and speech understanding in noise observed in earlier studies was also present in the more diverse clinical populations tested here. To answer this, we calculated the correlation between ACT values of the participants and their SRTns with the Off help level, i.e., when only amplification was provided in the hearing aids and MSI was deactivated. Among all 100 participants, the correlation was highly significant ($p < 0.001$) and of a similar size as the correlations obtained in previous studies with predecessors of ACT, with a Pearson's correlation coefficient $r = 0.70$. Importantly, the correlation remained highly significant when calculated for the German participants only ($r = 0.67$, $p < 0.001$) and for the Japanese participants only ($r = 0.85$, $p < 0.001$). These results confirmed that ACT is a meaningful proxy of speech-in-noise ability in ecologically valid settings when hearing-aid users are only provided amplification in their devices. Moreover, this can be expected to hold in clinical populations with different native languages and whose gain is adjusted and acoustic coupling chosen based on different fitting philosophies.

Having established that ACT was significantly related to speech-in-noise ability, the next analysis then investigated whether using ACT could lead to a better prediction of speech-in-noise ability than using the audiogram alone. The results of a multivariate regression analysis, illustrated in Figure 8, showed that ACT was the strongest and most significant predictor of the users' SRTns ($R^2 = 0.49$, $p < 0.001$), while the across-ear 4-frequency pure-tone average (PTA) was a moderately strong significant predictor ($R^2 = 0.40$, $p < 0.001$), and age was a weak but still significant predictor ($R^2 = 0.04$, $p = 0.043$). Thus, ACT alone could explain 49% of the variance in the users' SRTns. Combining ACT with the two other significant predictors above (PTA and age), it was possible to explain 59% of the variance in the users' SRTns, which is much higher than what was achievable with the audiogram alone (40%).

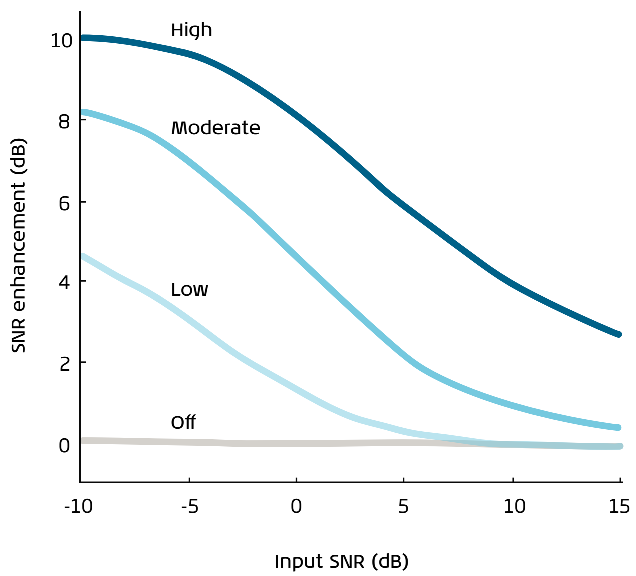

Figure 7: SNR enhancement provided by MoreSound Intelligence for the four tested help levels in noise (Off, Low, Moderate, High), measured with a head-and-torso simulator in the test set-up from Figure 6.

The combination of ACT values and PTA (and, to a much smaller extent, age) is thus clinically meaningful to predict an individual user's speech-in-noise ability more precisely. To illustrate this further, Figure 9 shows the relationship between the 100 participants' SRTns predicted from their audiogram, ACT values, and age, and their actual measured SRTns when wearing hearing aids with amplification only (Off help level). The correlation between the predicted and measured values was highly significant ($p < 0.001$), with a Pearson's correlation coefficient of 0.76. This correlation was also highly significant when calculated for the German participants only ($r = 0.80$, $p < 0.001$) and for the Japanese participants only ($r = 0.71$, $p < 0.001$).

Results: Test-retest reliability of ACT

Among hearing-aid users in this study, the within-subject test-retest standard deviation of the ACT paradigm was 0.96 dB within the same visit and 1.45 dB across visits. In comparison, the HINT test-retest standard deviation was found to be 0.92-0.95 dB within the same visit in hearing-impaired test participants (Nielsen & Dau, 2011; Laugesen et al., 2013). The intraclass correlation coefficient between the two same-day ACT measurements was 0.95, further indicating excellent reliability. Such a high test-retest reliability of ACT means that it is sufficient to perform the test once to obtain a reliable, clinically meaningful ACT value. The average test time in the study was found to be 100 seconds, which confirms that the ACT test is a fast, reliable test for clinical use, that can be expected to take only a few minutes including instructions and counselling.

The first ACT-based help-in-noise prescription for hearing aids

Based on the results from the multi-site clinical study described above, we developed a first ACT-based prescription of help-in-noise settings, compatible with Oticon hearing aids on Polaris R and newer platforms (i.e., Oticon Real and newer), specifically designed to provide an optimized first fit of MSI settings to individual users. The prescription considers the three most significant predictors of speech-in-noise ability as observed in the clinical trial, with the ACT value as the main contributor, the PTA as a second major contributor, and age as a minor contributor. As illustrated in Figure 10, the level of help in noise prescribed to a user of a given age with an available ACT value will thus depend on the severity of their contrast loss, as measured with ACT, and of their audibility loss, as measured with the audiogram. This will provide the audiologist with a more precise, objective, and personalised starting point for the settings available in the MoreSound Intelligence screen of the Genie 2 fitting software for the MSI functionalities that contribute the most to providing contrast between speech and noise.

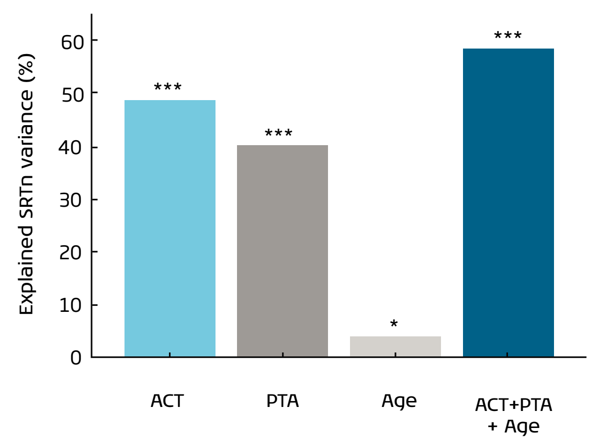

Figure 8: Percentage of the variance in SRTns explained by ACT, PTA, and age, used alone or in combination.
**** Model with strong statistical significance ($p < 0.001$).*
** Model with weak statistical significance ($p < 0.05$).*

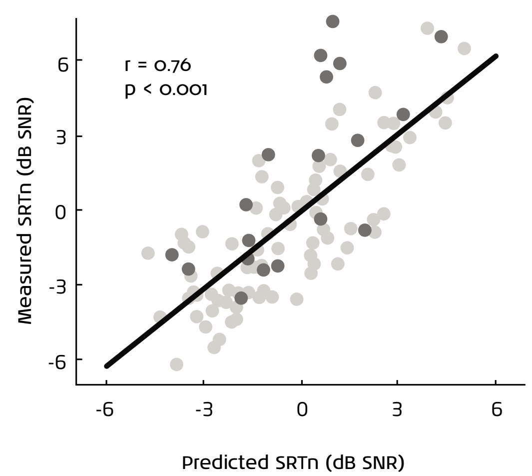

Figure 9: Relationship between 100 hearing-aid users' SRTns predicted from their audiogram, ACT values, and age, and their actual measured SRTns when wearing hearing-aids with amplification only (Off help level). German and Japanese participants are indicated by light grey and dark grey circles, respectively.

Results: Benefits of using an ACT-based help-in-noise prescription
Finally, we wanted to verify that it is indeed possible to use this first personalised prescription of MSI help-in-noise settings to provide the right contrast between speech and noise for users with different degrees of speech-in-noise ability. To test this, we first used the defined prescription formula based on ACT, PTA, and age to classify the users of the multi-site clinical study above into three groups:

- A first group with good speech-in-noise ability. The 15 users in this group are prescribed a lower MSI help level than default, towards the "Low" curve in Figure 7.

- A second group with fair speech-in-noise ability. The 51 users in this group are prescribed the default, moderate MSI help level, corresponding to the "Moderate" curve in Figure 7.

- A third group with poor speech-in-noise ability. The 34 users in this group are prescribed a higher MSI help level than default, towards the "High" curve in Figure 7.

We then compared how the SRTns of these three user groups changed when measured with 4 different MSI help levels (Off, Low, Moderate, and High), corresponding to the different help levels illustrated in Figure 7. These SRTns are shown in Figure 11. The grey area in the figure shows the performance range of young unaided normally hearing listeners. Ideally, the right "dosage" of help in noise in the hearing aids should be just enough to bring users within this range, so that their speech understanding in noise is within the normal-hearing range, without the need to process the incoming sound more than necessary for each user.

- For the user group with good speech-in-noise ability (left panel), the Low MSI help level is sufficient to reach the normal-hearing range.

- For the user group with fair speech-in-noise ability (middle panel), the Low help level is not sufficient and the default, Moderate MSI help level is needed to bring users within the normal-hearing range.

- For the user group with poor speech-in-noise ability (right panel), the High MSI help level is necessary to bring users as close as currently possible to the normal-hearing range. The fact that there is still some gap to reach normal performance in this group underlines the importance of providing these users as much help as possible in complex speech-in-noise situations.

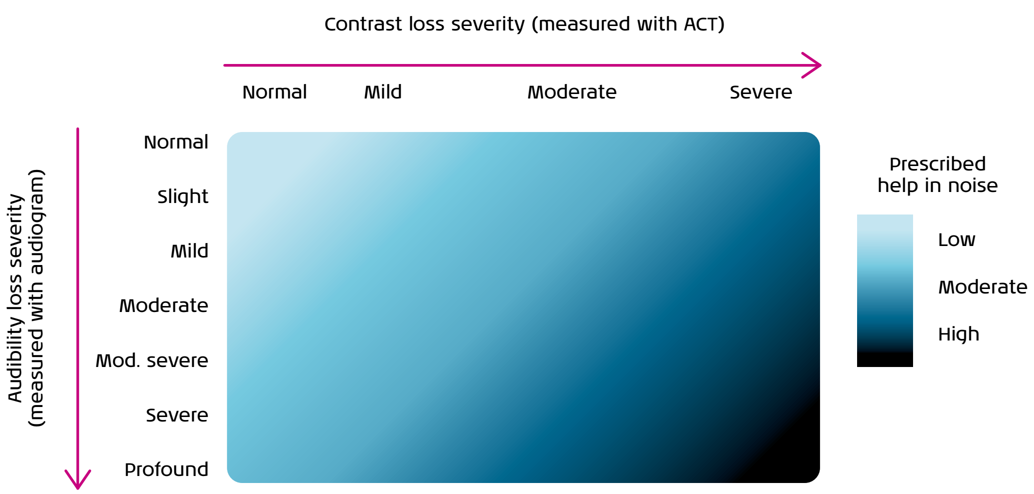

Figure 10: When using an ACT-based prescription, the level of help in noise provided to an individual user will depend on both their audibility loss and contrast loss severity.

These results provide evidence for an objective benefit of prescribing different levels of help in noise based on ACT, audiogram, and age. They demonstrate that estimating a user's contrast loss with ACT is clinically useful for hearing-aid fitting in addition to estimating their audibility loss with the audiogram. ACT helps to determine, on an individual basis, how much additional contrast between speech and noise the hearing aid should create for the user to have sufficient aided speech understanding in noise, without processing the incoming sound scene more than needed. In other words, ACT allows us to determine the appropriate dosage of the additional help in noise provided by the hearing aid. Ideally, this dosage should be high enough to allow the user's brain to process speech in noise as effortlessly as possible. It should also not be higher than needed to limit the risk of side effects, as some users may be more sensitive than others to strong processing of the incoming sound.

Using ACT for hearing-aid fitting in practice
The ACT test is now available in Interacoustics, MedRx, and GSI diagnostic equipment (ask your local provider for availability). In an upcoming release of the Oticon Genie 2 fitting software, the first evidence-based ACT prescription will be fully integrated into the fitting flow. The HCP will have the option of choosing ACT-based personalisation. If an ACT value is available in the HCP's user database, it will be read out directly by the fitting software. The HCP will also have the option to manually enter an ACT value. The prescribed help-in-noise settings will then be automatically applied to the hearing-aid fitting. If an ACT-based fitting is chosen, the first-fit settings in the MoreSound Intelligence screen in Genie 2 will thus be seamlessly adjusted to reflect the objectively predicted speech-in-noise difficulties of the user, while remaining adjustable for fine-tuning if needed. When using ACT-based personalisation, it is expected that about 50% of hearing-aid users will receive a different MSI setting than default, thus giving a better starting point for help in noise to a large proportion of users, especially to those with more severe difficulties in noise.

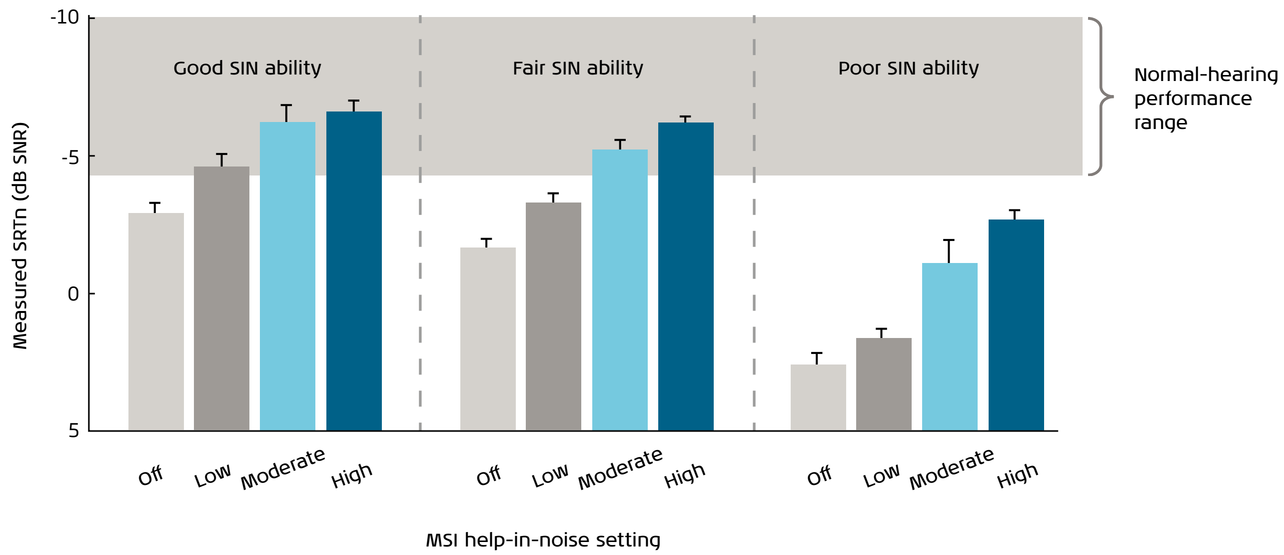

Figure 11: SRTns measured with 4 different MSI help levels in hearing-aid users classified into three groups based on their speech-in-noise (SIN) ability predicted from ACT, PTA, and age. The grey area indicates the performance range of young normal-hearing listeners without hearing aids. Error bars show the standard error of the mean.

Conclusion

Developed and optimised through more than a decade of scientific research, the Audible Contrast Threshold (ACT) test is a quick, objective, language-independent diagnostic test that helps to quantify speech-in-noise ability. It can be performed irrespective of a person's native language or language proficiency, using the same diagnostic equipment as used for tonal audiometry and with a similarly user-friendly procedure. The first large-scale international clinical study with ACT confirmed its highly significant relationship with speech-in-noise performance in ecologically valid settings in different clinical populations and its superior predictive power of speech-in-noise ability compared to the audiogram alone. While the audiogram is currently mainly used to prescribe hearing-aid gain, the addition of a single ACT measurement now enables an objective, evidence-based prescription of advanced help-in-noise features. In Oticon hearing aids on the Polaris R platform and onwards, the integration of the first ACT prescription rule into the Genie 2 fitting software will allow an automatic personalised first fit of advanced signal processing that provides contrast between speech and noise. With ACT, hearing-care professionals have a reliable tool to address, both in the diagnostic and fitting processes, the number-one complaint of people with hearing loss: hearing in noise.

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