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Brännström, Jonas; Lantz, Johannes; Nielsen, Lars Holme; Olsen, Steen Østergaard

Published in:
International Journal of Audiology

DOI:
10.3109/14992027.2011.609183

2012

Acceptable Noise Level with Danish, Swedish and non-semantic speech materials

K. Jonas Brännström[abd]

Johannes Lantz[d]

Lars Holme Nielsen[c]

Steen Østergaard Olsen[cd]

[a]Department of Clinical Science, Section of Logopedics, Phoniatrics and Audiology, Lund University, Lund, Sweden.

[b]Section of Audiology, ENT-department, Skåne University Hospital in Malmö, Sweden.

[c]Research Laboratory, Department of Otorhinolaryngology, Head and Neck Surgery, University Hospital, Rigshospitalet, Copenhagen, Denmark.

[d]HEARsound Laboratories, Network for Joint Hearing Research in the Oresunds Region.

Corresponding author: K. Jonas Brännström

Address: ENT-department

Section of audiology

SE-205 02 MALMÖ

Phone: +46(0)40-332205

E-mail: jonas.brannstrom@med.lu.se

Abstract

Objective: Acceptable Noise Level (ANL) has been established as a method to quantify the acceptance of background noise while listening to speech presented at the most comfortable level. The aim of the present study was to generate Danish, Swedish, and a non-semantic version of the ANL test and investigate normal-hearing Danish and Swedish subjects' performance on these tests. **Design:** ANL was measured using Danish and Swedish running speech with two different noises: Speech-weighted amplitude-modulated noise and multitalker speech babble. ANL was also measured using the non-semantic International Speech Test Signal (ISTS) as speech signal together with the speech-weighted amplitude-modulated noise. The latter condition was identical in both populations. **Study Sample:** Forty Danish and 40 Swedish normal-hearing subjects. **Results:** In both populations ANL results were similar to previously reported results from American studies. Generally, significant differences were seen between test conditions using different types of noise within ears in each population. Significant differences were seen for ANL across populations, also when the non-semantic ISTS was used as speech signal. **Conclusions:** The present findings indicate that there are extrinsic factors, such as instructions, affecting the ANL results.

Key words: Acceptable Noise Level, Danish, Swedish, International Speech Test Signal, Normal-hearing.

Abbreviations: ANL = Acceptable Noise Level, BNL = Background Noise Level, ILTASS = International Long-term Average Speech Spectrum, ISTS = International Speech Test Signal, MCL = Most Comfortable Level, PTA = Pure Tone Average, RMS = Root-Mean-Square, SPL = Sound Pressure Level

Introduction

Nabelek and colleagues (1991) developed a method to quantify the amount of background noise that subjects accept when listening to speech. They called the method acceptable noise level (ANL) and they stated that 'The acceptable noise level (ANL), expressed in decibels, is defined as a difference between the most comfortable listening level [MCL] for speech and the highest background noise level [BNL] that is acceptable when listening to and following a story.' (Nabelek et al., 2004). The ANL is calculated by subtracting the BNL from the MCL (MCL-BNL=ANL), which means that subjects with high acceptance for background noises have a low ANL (e.g. 3 dB) while subjects with low acceptance has a high ANL (e.g. 17 dB) (Nabelek et al., 2004). There are currently no Danish or Swedish versions of the ANL test available for research or clinical use.

Previous studies have shown that the ANL has a high test-retest reliability (Freyaldenhoven et al., 2006). ANL has been tested on populations of different ages that all showed similar distributions (i.e. mean and standard deviations, SD) (e.g. Nabelek et al., 1991; Rogers et al., 2003); this suggests that ANL measures an intrinsic property of the individual subject. However, there is considerable variation in ANL across subjects (e.g. Nabelek et al., 1991; Nabelek et al., 2004; Freyaldenhoven et al., 2006). ANL has been established within the range 1-28 dB in normal hearing subjects using mainly an American speech material and different types of noise signals (Nabelek et al., 1991; Rogers et al., 2003; Franklin et al., 2006; Freyaldenhoven et al., 2006; Harkrider & Tampas, 2006; Tampas & Harkrider, 2006; von Hapsburg & Bahng, 2006; Freyaldenhoven et al., 2007; Gordon-Hickey & Moore, 2007; Plyler et al., 2008), but no plausible explanation for this variation has been provided yet (Nabelek et al., 1991; Rogers et al., 2003; Nabelek et al., 2004; Harkrider & Smith, 2005; Freyaldenhoven et al., 2006; Harkrider & Tampas, 2006; Gordon-Hickey & Moore, 2007).

Furthermore, ANL does not seem to be related to the language of the speech signal in normal-hearing bilingual listeners and this indicates that it is an intrinsic characteristic of the individual subject that does not depend on the semantic properties of the signal (von Hapsburg & Bahng, 2006). On the other hand, in a study by Gordon-Hickey and Moore (2008) the effect of the intelligibility of the speech signal on ANL was assessed using intelligible speech, the same speech reversed, and speech in a language unfamiliar to the subjects. It was shown that the ANL was slightly but significantly poorer (i.e. higher) for the conditions using reversed and unfamiliar speech compared to intelligible. This indicates that the intelligibility of the speech signal may affect ANL. However, a more appropriate method to maintain the naturalness of the speech signal, while avoiding the use of a unfamiliar language, and at the same time remove all semantic content could be obtained by using the International Speech Test Signal (ISTS) (Holube et al., 2010) as speech signal in the ANL test. Using ISTS potentially also allows for direct comparisons between test sites where the subjects speak different languages.

The present study reports the generation of both Danish and Swedish versions of the ANL test and the performance of normal-hearing subjects on these tests. It also examines the effect of using ISTS as speech signal. Based on previous findings that generally suggest that ANL is an intrinsic property of the individual subject, we hypothesise that ANL results for our national versions of the ANL test closely resemble those previously reported. Secondly, we hypothesise that ANL using the ISTS, a speech like signal without semantic content, provide similar results in both studied populations.

Material and methods

Fifty-five Danish and 46 Swedish subjects were initially recruited to the study. The subjects were university students, colleagues, family and friends of the authors. Ten Danish and 6 Swedish subjects did not meet the inclusion criteria (see below) and were thus excluded. All Danish subjects were tested at the Department of Otorhinolaryngology, Head and Neck Surgery, University Hospital, Rigshospitalet in Copenhagen, Denmark, and all Swedish subjects were tested at the Section of Audiology, ENT-department, Skåne University Hospital in Malmö, Sweden. To be included the subjects had to have normal tympanograms (< ± 150 daPa) according to Margolis and Goycoolea (1993) and recordable ipsi- or contralateral acoustic reflexes at 1 kHz; these measurements were conducted using either a Madsen Electronics Zodiac 901 Middle-ear Analyzer or a Madsen OTOflex 100 (Danish subjects) or a GSI Tympstar (Swedish subjects). One of the recruited Danish subjects did not show recordable acoustic reflexes and was excluded. Pure-tone audiometry was performed on all subjects using Madsen Astera Audiometers with Sennheiser HDA 200 circumaural earphones (see section *Equipment* for calibration details). The audiometry was conducted in accordance with ISO 8253-1 (ISO, 1998) using the manual ascending technique (-10/+5 dB). To be included, the subjects had to have pure-tone hearing thresholds ≤ 15 dB HL (ISO, 2004) for octave frequencies 250 to 4000 Hz. Fourteen Danish and six Swedish subjects did not meet the hearing threshold inclusion criterion, and one Danish subject did not meet the acoustic reflex criterion. In total after exclusion, 40 Danish and 40 Swedish subjects participated in the study. Normal external ear canals and tympanic membranes were also verified in all subjects by otoscopy. Demographic data on these subjects are presented in Table I. It can be seen that there is a predominance of female subjects in both the Danish and Swedish populations, although the gender difference is less pronounced in the Danish population. The equipment used for audiometry was also used for the ANL testing. All investigations were performed in accordance with the Helsinki declaration. The subjects received a symbolic gift for their participation. The Scientific Ethical Review Board C for the Capital Region approved the Danish part of the project (H-C-2009-022) and the Regional Ethical Review Board in Lund approved the Swedish part of the project (2010/240).

Speech and noise signals

The ANL stimuli consisted of a speech signal in one channel and a noise signal in the other channel presented monaurally to the same earphone. These signals were pre-recorded and implemented in the audiometer software as integrated speech stimulus files. For both the Danish and Swedish parts of the study three test conditions were used; (1) running speech and speech-weighted amplitude-modulated noise, (2) running speech and multitalker speech babble, and (3) ISTS and speech-weighted amplitude-modulated noise.

In the Danish part of the study the running speech signal from the Dantale audio compact disc (track 12) was used as speech signal in conditions 1 and 2. This speech material and its recording is described in detail by Elberling and colleagues (1989) and consists of a geographic and historical description (Andersen, 1983) read by a female speaker. The duration of the recording is 4 minutes and 23 seconds and contains on average about 40 syllables per 10 seconds. Also, approximately 16% of the total duration is silence (i.e. pauses). The signal is low-pass filtered at 10 000 Hz. The running speech in the Swedish part of the study in conditions 1 and 2 was an excerpt from the audio recording of the book "Priset på vatten i Finistère" (The price of water in Finistère, CD 1, track 6) read by the female author (Malmsten, 2003). The duration of the recording is 4 minutes and 7 seconds, contains on average about 30 syllables per 10 seconds and approximately 19 % of the total duration is silence. The signal was low-pass filtered at 10 029 Hz to resemble the Danish speech signal.

The band stop was set to 10 072 Hz and attenuation was set to 100 %. This resulted in a steeper filter function and more attenuation in higher frequencies for the Swedish speech signal than in the Danish, as seen in Figure 1. In condition 3 the ISTS was used as speech signal. The generation of the ISTS has been described in detail by Holube et al. (2010). In summary, ISTS contains concatenated syllables from six selected female speakers of six different languages (Arabic, English, French, German, Mandarin, and Spanish) reading the story “The North Wind and the Sun”. The recordings were first filtered to match the International Long-term Average Speech Spectrum (ILTASS) (Byrne et al., 1994) and then split into segments, roughly approximating one syllable. Segments from the different languages were then concatenated into utterances closely resembling running speech according to strict rules. The ISTS contains on average about 40 syllables per 10 seconds and approximately 17 % of the total duration is silence. The final properties of the ISTS are quite similar to those seen in the original recordings (Holube et al., 2010). The 16-bit version of the ISTS was used (the completely unfiltered original file). The original duration of the signal is 60 seconds, but the test signal used in the present study consisted of four consecutive presentations of the ISTS, i.e. the used signal was 4 minutes long.

In both the Danish and Swedish parts of the study the noise from the Dantale audio compact disc (track 12, Dantale noise) was used as noise signal in conditions 1 and 3. The Dantale noise and its recording has been described in detail by Elberling and colleagues (1989). This noise is speech-spectrum shaped and generated from band-pass filtered white noise. The noise is amplitude-modulated using a band-pass filtered white noise at 4 Hz and has a modulation depth of approximately 27 %. In the following the Dantale noise is referred to as speech-weighted noise. In condition 2, the ANL multitalker (12 voices) speech-babble noise was used. This noise was taken from the official ANL CD (Arizona Travelodge, Cosmos

Distributing Inc.) which in turn is identical to the noise used in the Revised Speech in Noise Test by Bilger et al. (1984).

The signals were extracted from their digital sources and assembled using the computer software Adobe Audition (version 3.0). A sampling rate of 44 100 Hz was used. The long-term envelope spectra (Digital Fourier Transform using 256 points and Blackmann window) for the speech signals and noises used are presented in Figure 1. The average RMS-values for these signals were equalised and all showed levels of about -20 dB (see Table II). As seen in Figure 1, all speech signals closely resemble each other for frequencies below 10 000 Hz. This means that they all have a frequency content that is similar to the ILTASS. Above 10 000 Hz the ISTS has some frequency content while the Danish and Swedish speech signals show quite low amplitudes; the differences seen between the Danish and Swedish speech signals should, theoretically, not contribute to differences in overall loudness. It can also be seen in Figure 1 that the ANL babble noise is quite similar to the speech signals and contains more energy in higher frequencies than the speech-weighted noise.

Equipment and calibration for pure-tone audiometry and ANL

The complete equipment set-ups (Astera Audiometer and the HDA 200 earphones) in both Denmark and Sweden were calibrated before the study started in accordance with IEC 60318-2, ISO 389-5, and ISO 389-8 using the same Brüel and Kjaer 2610 measuring amplifier with a 4144 microphone in a 4152 ear simulator (IEC, 1998; ISO, 2004; ISO, 2006). A frequency-modulated 1000 Hz calibration tone (modulation rate = 20 Hz, modulation frequency = 250 Hz) with a 10 dB higher average RMS (see Table II) than the speech and noise signals was used for the calibration of these signals. The actual output levels of the speech and noise signals presented through the transducers were also verified using the same calibration equipment and all signals showed the same average dB SPL RMS ± 1 dB (averaging time was 20 seconds) at identical audiometer output settings. All tests were performed in double-walled soundproof booths (complying with the maximum permissible ambient sound pressure levels as specified in ISO 8253-1) during one session.

Procedures

A short interview was initially conducted to ascertain that the subject was otologically healthy. Otoscopy and immittance measurements followed and then pure-tone audiometry. Finally, ANL measurements were made.

Both written and oral instructions were given prior to ANL testing. The instructions were Danish and Swedish versions of the English instructions (Nabelek, 1991; Rogers et al., 2003; Nabelek et al., 2004; Nabelek et al., 2006). The complete Danish and Swedish instructions are presented in Appendices A and B. The instructions were discussed with the subject, and examples of speech and noise were presented. The subjects were instructed to listen to the speech signal in quiet presented monaurally through the earphones and, after a few moments of listening, to adjust the sound level to the MCL using an up-and-down procedure; the subject used the audiometer attenuators (without any visual feedback) to increase the loudness until the speech signal became too loud, then decrease it until it became too soft, and finally the subject selected the loudness level that was most comfortable for himself (MCL). The subject indicated to the examiner when he had found the MCL. After the MCL was identified, BNL was established by adding a noise signal in the same earphone as the speech signal and the subject was instructed to repeat a similar procedure; the speech signal remained fixed at the previously established MCL and the subject increased the loudness of the noise until it became too loud, then decreased it until the speech became very clear, and finally the subject selected the loudness level (i.e. BNL) that the subject could accept or “put up with” without becoming tense or tired while following the speech signal for a long time. The complete procedure (both MCL and BNL) was repeated three times for each test condition in each ear and both ears were tested in all subjects. In each repetition, the initial stimulus level for both speech and noise signals was 58 dB SPL for Danish subjects and 48 dB SPL for Swedish subjects. The difference seen in initial stimulus levels was unintentional. A fixed initial stimulus level of the noise was selected according to the American user instructions for the ANL stating that initial presentation levels for MCL and BNL should be identical. All adjustments were made using a 2 dB step size for both MCL and BNL. The test condition presentation order and test ear order was balanced across subjects according to a Latin squares design.

Statistical analysis

Reported data consists of MCL, BNL, and ANL for the three tested conditions. ANL (in dB) was calculated as the difference between the MCL (dB SPL) and the BNL (dB SPL). This was done for each repetition in a test condition. The reported results are the averages and standard deviations (SD) of these three repetitions. MCL, BNL, and ANL differences *between ears* in each population were explored using a paired-samples T-test; alpha levels <0.01 were considered statistically significant (Altman, 1999). A two independent-samples T-test was used to explore gender differences in each population; the same alpha level was used as for the paired-samples test. Repeated measures analyses of variance (ANOVA) were used to evaluate the effects of test condition and test repetition separately for MCL, BNL, and ANL within and between populations in one ear at the time; alpha levels < 0.01 were considered statistically significant. In each analysis, one between-subject variable was used (group, i.e. Danish and Swedish populations), one within-subject variable (test condition; condition 1, 2, and 3 or test repetition: repetition 1, 2, and 3), and interaction effects. Significant differences displayed in the ANOVA were further explored using post hoc T-tests; alpha levels < 0.01 after Bonferroni correction were considered statistically significant. Pearson's correlation coefficient (rho) was calculated between the collected variables to investigate associations. Probability values of $p<0.01$ were considered statistically significant. Single measure intraclass correlation coefficients were calculated between the separate repetitions of MCLs, BNLs, and ANLs to estimate the test-retest reliability within each population. This was made separately for each test condition. Parametric tests were used since MCL, BNL, and ANL results in each repetition for both the Danish and Swedish subjects were found to be normally distributed using the Kolmogorov-Smirnov test for normality.

Results

The averages, ranges, and SDs for MCL, BNL, and ANL in the three test conditions are presented in Table III and Figures 2a-c for all subjects. In a similar manner, the results for female and male subjects are shown in Table IV (ranges are omitted to increase readability). The intraclass correlation coefficients are shown in Table V.

Test reliability

As seen in Table V, for each population the intraclass correlation coefficients indicated high test-retest reliability of MCL, BNL, ANL across repetitions within each test condition. Test-retest reliability was also assessed within each population using repeated measures ANOVA examining the within-subject main effects of test repetition for MCL, BNL, and ANL in each test condition and ear. Overall, no significant interaction effects were observed. No significant main effects were seen in any population for MCL, BNL, or ANL test repetition, although one exception was seen: For the Swedish population a significant within-subject main effect was seen for BNL in condition 2 in the right ear only ($F[8.13]$, $p = 0.002$). The pairwise post hoc comparisons showed that the results for test repetition 1 were significantly lower (52.7 dB SPL) than for repetition 3 (55.8 dB SPL). Also, as shown in Table III, similar SDs and ranges for MCLs and BNLs were seen in all conditions for both populations. There is also a tendency in both populations that the SDs were lower in condition 3 than the other conditions.

In Table III, it can be seen that there were a significant within-subject main effect in the left ear for MCL ($F[9.60]$, $p < 0.001$) for test condition. No significant interaction effects were observed. Further pairwise post hoc analysis showed that condition 3 was significantly lower than condition 1 ($p = 0.005$) and 2 ($p <0.001$) for the Danish population only. Also, significant within-subject main effects can be seen for BNL in left ($F[21.29]$, $p < 0.001$) and right ear ($F[21.47]$, $p < 0.001$). Post hoc analyses revealed that condition 2 was significantly lower than condition 1 ($p < 0.001$) and 3 ($p < 0.001$) in both ears for the Danish population. Also, condition 2 was significantly lower than condition 1 in the left ($p < 0.001$) and right ear ($p = 0.004$) for the Swedish population. As shown in Table III, there were significant within-subject main effects for ANL test condition in both left ($F[74.34]$, $p < 0.001$) and right ear ($F[46.80]$, $p < 0.001$). As demonstrated in Table III, further post hoc analyses showed that for both populations ANL was significantly higher (i.e. poorer) in condition 2 than in the other two conditions ($p < 0.001$). Also shown in Table III, condition 3 was significantly lower than condition 1 for the Danish population but in the left ear only ($p < 0.001$).

Danish study

Generally, for the Danish subjects, similar averages, SDs, and ranges were seen for MCLs, BNLs, and ANLs between ears for the separate test conditions and the minor average differences seen were not significant. No significant gender differences were found for MCL, BNL, or ANL in any ear. The correlation analysis using Pearson's rho showed that within each ear the MCLs in the different conditions were highly associated to each other (degrees of freedom, DF, = 5, rho ≥ 0.909, $p < 0.001$). A similar association was seen for BNLs (DF, = 5, rho ≥ 0.849, $p < 0.001$) within each ear. Also ANLs in the different conditions were highly associated to each other (DF, = 5, rho ≥ 0.849, $p \leq 0.001$) within each ear. This suggests that subjects with high MCL, BNL, and ANL in one test condition also have high MCL, BNL, and ANL in the other test conditions and vice versa. The linear associations for the ANL results are demonstrated in the left column of Figure 3; note that data for both ears are shown. Positive associations were also seen between results in left and right ears for MCL (DF = 5, rho ≥ 0.855, $p < 0.001$), BNL (DF = 5, rho ≥ 0.873, $p < 0.001$), and ANL (DF = 5, rho $\geq$ 0.840, $p \leq 0.001$) for each test condition suggesting that subjects with high ANL in one ear has a high ANL in the other ear as well. No associations were observed between age, PTA in left or right ear, and MCL, BNL, or ANL results. A significant association was seen between age and PTA in the right ear (DF =10, rho = 0.451, $p = 0.004$).

Swedish study

Also for the Swedish subjects, similar averages, SDs, and ranges were seen for MCLs, BNLs, and ANLs between ears for the separate test conditions and the minor average differences seen were not significant. No significant gender differences were found for MCL, BNL, or ANL in any ear. In the correlation analysis (Pearson's rho), it was shown that within each ear the MCLs in the different conditions were associated to each other (DF, = 5, rho ≥ 0.845, $p <$

0.01). This was also seen for BNLs within each ear (DF, = 5, rho ≥ 0.879, p < 0.01). Furthermore, ANLs in the different conditions were associated to each other within each ear (DF, = 5, rho ≥ 0.869, p ≤ 0.01). As in the Danish part of the study, this suggests that subjects with high MCL, BNL, or ANL in one test condition also have high MCL, BNL, or ANL in the other test conditions and vice versa. The linear associations between the three ANL conditions are presented in the right column of Figure 3; note that data for both ears are shown. Positive associations were also seen between results in left and right ears for MCL (DF = 5, rho ≥ 0.903, p < 0.01), BNL (DF = 5, rho ≥ 0.922, p < 0.01), and ANL (DF = 5, rho ≥ 0.905, p ≤ 0.01) for each test condition. As in the Danish part of the study, this indicates that subjects with high MCL, BNL, or ANL in one ear have a high MCL, BNL, or ANL in the other ear as well. No associations were seen between age, PTA in left or right ear, and MCL, BNL, or ANL results, although one exception was seen; a significant negative association was seen between age and BNL in left ear for condition 3 (DF=20, rho = -0.437, p = 0.005). No significant associations were seen between age and PTA in any ear.

Comparisons between Danish and Swedish results

As seen in Table I, the Danish subjects were older on average and had a slightly poorer average PTA in both ears. The age difference was significant (p = 0.003). As shown in Table III and Figures 2a-c, there were no significant between-subjects effects for MCL and BNL in the different test conditions between Danish and Swedish participants. However, there were significant between-subjects effects for the ANL results for the different test conditions in both left (F[8.56], p = 0.004) and right (F[7.74], p = 0.007) ear. As seen in Table III, this finding indicates that the Danish ANL results were significantly higher (i.e. poorer) than the Swedish in all test conditions. Also, there is a tendency for the Swedish subjects to show larger SDs for MCL and BNL than the Danish, but smaller SDs for ANL results. Ranges were similar across populations.

Discussion

The present study reports the generation of Danish and Swedish ANL tests and investigates normal-hearing Danish and Swedish subjects' performance on these tests. Average ANLs have been previously reported between 1 and 28 dB in normal-hearing subjects using the same number of repetitions, often identical step-sizes, and threshold criterions (Nabelek et al., 1991; Rogers et al., 2003; Franklin et al., 2006; Freyaldenhoven et al., 2006; Harkrider & Tampas, 2006; Tampas & Harkrider, 2006; von Hapsburg & Bahng, 2006; Freyaldenhoven et al., 2007; Gordon-Hickey & Moore, 2007; Plyler et al., 2008). In the present study, we found average ANLs between 5.6 and 16.6 dB depending on study population (Danish or Swedish) and test condition. This is a finding similar to previously reported. Again, we found SDs for ANL between 6.9 dB and 10.2 dB also depending on study population and test condition, which is similar to SDs previously reported that ranged between 1.7 and 11.0 dB for normal-hearing subjects (Nabelek et al., 1991; Rogers et al., 2003; Franklin et al., 2006; Freyaldenhoven et al., 2006; Harkrider & Tampas, 2006; Tampas & Harkrider, 2006; von Hapsburg & Bahng, 2006; Freyaldenhoven et al., 2007). Furthermore, as in previous studies (Nabelek et al., 1991; Rogers et al., 2003), we found no associations between ANL and age or PTA. This could imply that the Danish and Swedish ANL tests behave as the American version of the ANL. However, there are significant differences between the Danish and Swedish results that suggest that there are several difficulties in comparing ANL results across languages and possibly also across test sites.

Generally, significant differences were seen in average ANL between the Danish and Swedish subjects. This finding could be a result of differences in the speech materials used. Although the average RMS (measured both electrically and as coupler sound pressure level) and the overall frequency contents of the Danish and Swedish speech signals are quite similar for frequencies below 10 000 Hz (see Figure 1), there are substantial differences in their dynamic properties such as lower number of syllables per time unit and more pauses in the Swedish speech signal compared to the Danish speech signal. A lower syllable rate indicates a slower speaker and, together with more pauses, the momentary sound pressure levels of the Swedish speech signal could actually be higher than the Danish. Furthermore, when adding noise to the speech, these short term differences could result in a better signal-to-noise ratio in the Swedish speech signal. Hence, the relatively higher BNL and lower ANL in the Swedish results may theoretically be caused by a better short term signal-to-noise ratio for the Swedish speech and noise signals.

Although there are differences in energy content in frequencies above 10 000 Hz, the differences seem not to have affected the overall loudness of the signals. On the other hand, Johnson and colleagues (2009) showed that the ANL increased with increasing bandwidths up to 9 000 Hz in subjects with mild sensorineural hearing losses indicating that subjects require larger signal-to-noise ratios when broader signals are used. In the present study, the Danish speech has more high-frequency content than the Swedish (cf. Figure 1) and thus the higher ANL seen in the Danish subjects may be a result of the differences in frequency contents of the test signals. However, the findings in the study by Johnson and colleagues (2009) may not be applicable on normal-hearing subjects. Furthermore, there are no significant differences in MCL between the two populations which might be expected if there were large enough differences between the speech signals. Previous studies have also shown that the BNL decreases and ANL increases with increasing MCL (Franklin et al., 2006; Tampas & Harkrider, 2006) and there is also a difference in initial stimulus level between the Danish and Swedish parts of the study that could also have affected the results. Again, since we recorded no differences in MCL levels across countries, these are perhaps less probable causes of the ANL differences seen. Furthermore, the Danish population had a higher mean age than the Swedish. This could indicate that ANL is affected by age. However, this seems unlikely since no previous studies have reported this finding. Also, there was a slight difference in the instructions for the BNL. Danish and Swedish languages are quite similar in their written forms. In the Danish translation the word “følge” (follow) was used but in the Swedish translation the word “lyssna” (listen) was used. There is a semantic difference between these two words, but in relation to the task stated in the BNL instructions the effect of this difference should be marginal.

The differences demonstrated in the present study could thus be influenced by differences in the composition of the speech signals used and their interaction with the two types of noise used. To account for these differences we removed the semantic content of the speech signal (by using ISTS as speech signal) and presented it with the speech-weighted noise; hence, this test condition was identical for both Danish and Swedish subjects. Using this non-semantic signal we found that the differences in average BNL and ANL were slightly reduced across populations, but there was still a significant ANL difference between subjects from the two countries. This finding suggests that ANL is influenced by extrinsic factors such as examiner attitude, instructions and/or cultural differences in acceptance of background noise. This poses a problem for the comparison of ANL across languages and perhaps also across test sites even when using non-semantic speech signals.

In previous studies, several factors and auditory functions of the subjects have been examined to provide explanations for the large individual differences seen in ANL. The variation in ANL has been shown to not depend on age (Nabelek et al., 1991), gender (Rogers et al., 2003), hearing sensitivity (e.g. Nabelek et al., 1991; Nabelek et al., 2004; Harkrider & Smith, 2005; Freyaldenhoven et al., 2006; Gordon-Hickey & Moore, 2007), middle ear function (Harkrider & Smith, 2005), outer hair cell function (click evoked otoacoustic emissions) (Harkrider & Smith, 2005), or the efferent pathways utilising the medial olivocochlear bundle (contralateral suppression of otoacoustic emissions and contralateral stimulation of the acoustic reflex) (Harkrider & Smith, 2005). ANL seems not to be generally related to speech recognition scores in noise (Bilger et al., 1984) in normal-hearing or hearing-impaired subjects (Nabelek et al., 2004; Nabelek et al., 2006; von Hapsburg & Bahng, 2006). This suggests that speech perception in noise taps into a different aspect of listening in noise than ANL processing and has been taken as evidence that acceptance of background noise is an intrinsic characteristic of the individual subject. Furthermore, it is uncertain whether the type of noise used affects the ANL; Nabelek and colleagues (1991) showed no effect, but Freyaldenhoven et al. (2006) found that the average ANL is influenced by noise type. The latter finding could suggest that ANL measured with different types of noise cannot be compared directly. In the present study, we also found significant differences in ANL within each study population using speech-weighted noise or babble noise, which also suggests that ANL is affected by the type of noise used. Also, Tampas and Harkrider (2006) compared differences between two groups of young normal-hearing females - one with high ANL ($\geq$ 16 dB) and one with low ANL ($\leq$ 6 dB) - in electrophysiological responses of the auditory system measured as auditory brainstem responses, middle latency responses, and late latency responses. They showed that the group with high ANL had significantly larger normalised amplitude responses and shorter latencies than the group with low ANL (Tampas &

Harkrider, 2006). This suggests that the magnitude of ANL is linked to unexplored auditory functions as expressed through electrophysiological responses. However, the indication, that examiner attitude, instructions and/or cultural differences have affected the present results, could provide at least a partial explanation for the individual differences in ANL seen in normal-hearing subjects and the quite large differences in average ANLs seen between previous studies using the same speech materials (Nabelek et al., 1991; Rogers et al., 2003; Harkrider & Smith, 2005; Franklin et al., 2006; Harkrider & Tampas, 2006; Tampas & Harkrider, 2006; von Hapsburg & Bahng, 2006; Freyaldenhoven et al., 2007; Gordon-Hickey & Moore, 2007; Plyler et al., 2008).

On the other hand, we found significant positive associations between MCL, BNL and ANL results in the three test conditions in both ears for both study populations. This indicates that subjects with low MCL, BNL, and ANL in one condition have low values in the other conditions and vice versa. Also, we found high test-retest reliability for separate repetitions within test conditions. On the other hand, comparing the results in the different test conditions for both studied populations separately did not show any significant differences in average MCL in each ear, but in average BNL and ANL in each ear. More specifically, condition 2 using babble noise resulted in lower BNLs and higher (i.e. poorer) ANLs in both populations. These findings together suggest that test conditions 1 and 2 using the same speech-weighted amplitude-modulated noise seem almost interchangeable in both languages at the separate test sites. However, there is a trend in both studied populations that ANL is lower and the SD is smaller when assessed using ISTS as speech signal in speech-weighted noise. This could indicate that the ANL test has a linguistic component and that the removal of semantic content improves the reliability of the test. This supports the findings of Gordon-Hickey and Moore (2008) that also found that the semantic content of the speech signal affected the ANL.

However, they found that ANL became significantly poorer using reversed or unfamiliar language as speech signal compared to intelligible speech, which in that part contradicts the present finding. The cause of these differences in results is difficult to explain without further studies. But since the ANL SDs decreased for the non-semantic speech signal, the use of ISTS as the speech signal when testing ANL can be recommended over semantic speech signals to facilitate the comparison between studies keeping the present discussion in mind.

Conclusion

The Danish and Swedish versions of the ANL test seems to provide ANL results similar to those previously reported for normal-hearing subjects using an American version of the ANL test. Generally, there are significant differences between the different test conditions within each population that depends on the type of noise used. However, there are significant differences in ANL results between the Danish and Swedish populations that could be an effect of differences in speaker rate and high-frequency content in relation to the noises used. After removing the semantic content of the speech signal by using the ISTS as speech signal and the same noise in both populations, differences remained between the populations for ANL although the differences were reduced. This indicates that there are extrinsic factors, such as examiner attitude and instructions, which affect the ANL results. Further research using different types of speech-like noises can possibly provide more information on the underlying factors affecting the test.

Declaration of interest

No outside funding or grants in support of this research were received. The authors report no conflicts of interests. The authors alone are responsible for the content and writing of the paper.

Acknowledgements

The authors are indebted to engineer Arne Månsson at Rigshospitalet in Copenhagen for valuable discussions and advices regarding equipment calibration, Anders H Rasmussen for integrating the test signals in the audiometric software, and audiologist Edita Zunic that collected most of the Swedish data. The authors are also indebted to two anonymous reviewers for valuable comments and suggestions to this manuscript.

Appendix A. Danish instructions for the test of Acceptable Noise Level (ANL)

1) Indstilling af tale (MCL)

Du skal lytte til en historie i hovedtelefonen. Når du har lyttet et øjeblik, vil vi bede dig om at indstille lydstyrken på historien, så den er mest behagelig - ligesom når du lytter til radio. Vi giver dig en knap, så du kan skrue op eller ned for lyden i små trin. Skru først op for talen så den bliver for kraftig og derefter ned, så den bliver for svag. Derefter skal du indstille lydstyrken, så den er mest behagelig for dig. Sig til når du har fundet det mest behagelige niveau.

2) Indstilling af støj (BNL)

Du skal nu lytte til historien igen, men denne gang i baggrundsstøj. Når du har lyttet et øjeblik, vil vi bede dig om at finde den KRAFTIGSTE lydstyrke på baggrundsstøjen, som du vil kunne acceptere uden at anstrenge dig og uden at blive træt, mens du lytter til historien. Skru først så højt op for baggrundsstøjen, at den bliver for kraftig og skru derefter så langt ned for støjen, at talen bliver meget klar og tydelig. Indstil til sidst støjens lydstyrke (op eller ned) til det KRAFTIGSTE niveau, som du vil kunne acceptere, hvis du i lang tid skal følge historien. Sig til når du har fundet det korrekte niveau.

Appendix B – Swedish instructions for the test of Acceptable Noise Level (ANL)

1) Inställning av tal (MCL)

Du ska lyssna till en historia i hörlurarna. När du lyssnat helt kort, vill vi be dig ställa in ljudstyrkan på historien, så att den är mest behaglig - precis som när du lyssnar på radio. Vi ger dig en knapp, så du kan skruva upp eller ner ljuden i små steg. Skruva först upp talet så att det blir för starkt och därefter ner så att det blir för svagt. Därefter ska du ställa in ljudstyrkan, så den blir mest behaglig för dig. Säg till när du hittat den mest behagliga nivån.

2) Inställning av brus (BNL)

Du ska nu lyssna till historien, men denna gång i ett bakgrundsbrus. När du lyssnat helt kort, vill vi be dig att hitta den STARKASTE ljudstyrkan på bakgrundsbruset, som du kan acceptera utan att anstränga dig och utan att bli trött, medan du lyssnar på historien. Skruva först upp bakgrundsbruset så att det blir för starkt och skruva sedan ner bruset så mycket att talet blir mycket klart och tydligt. Till sist, ställ in bruset ljudstyrka (upp eller ner) till den STARKASTE nivån, som du skulle acceptera, om du skulle lyssna till historien en längre stund. Säg till när du funnit den korrekta nivån.

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Table I. Demographic data for all subjects (n=80).

Variable			**Danish subjects (n=40)**		**Swedish subjects (n=40)**	
Age (years)		Mean	34		27,9	
		SD	10,2		7,4	
		Range	19-56		19-49	
Gender		Female	60,0%	(n=24)	77,5%	(n=31)
		Male	40,0%	(n=16)	22,5%	(n=9)
PTA (dB HL)	Right ear	Mean	2,7		2	
		SD	3,6		2,8	
		Range	-5-13		-4 - 8	
	Left ear	Mean	2,3		1,5	
		SD	3,9		3,4	
		Range	-5-11		-5 - 8	

PTA was calculated as the average in dB HL for frequencies 0.5, 1, 2, and 4 kHz.

Table II. The average RMS-values for the test signals measured on the electrical output. The dB-reference indicates maximum level on sound card.

	Average RMS
Danish speech	-20,0 dB
Swedish speech	-20,0 dB
ISTS	-20,0 dB
Dantale speech-weighted noise	-19,7 dB
ANL babble noise	-19,6 dB
Calibration tone (1000 Hz)	-10,0 dB

Table III. Mean (M), standard deviation (SD), and ranges of MCL, BNL, and ANL for the Danish (D) and Swedish (S) subjects for the three test conditions. F-values show the between (B) population effects and within (W) population main effects. Significant effects were post hoc analysed and significant ones are shown as ** (p<0.01) or *** (p<0.001) at given condition. N.s.=not significant.

			Danish subjects (n=40)		**Swedish subjects (n=40)**		**Right ear: Condition1-2-3**				**Left ear: Condition1-2-3**			
			Right ear	**Left ear**	**Right ear**	**Left ear**	**F-value**	**C1-2**	**C1-3**	**C2-3**	**F-value**	**C1-2**	**C1-3**	**C2-3**
Condition 1: Running speech and Dantale noise	**MCL**	M	63,6	64,0	65,0	64,6	B: n.s.				B: n.s.			
		SD	9,1	10,0	11,6	11,7	W: n.s.				W: 9.601***	D: n.s.	D**	D***
		Range	47-93	43-99	35-86	37-88						S: n.s.	S: n.s.	S: n.s.
	BNL	M	50,6	51,4	57,4	58,2	B: n.s.				B: n.s.			
		SD	10,3	11,8	14,6	14,8	W: 21.473***	D***	D: n.s.	D***	W: 21.293***	D***	D: n.s.	D***
		Range	35-87	28-94	23-85	28-92		S**	S: n.s.	S: n.s.		S***	S: n.s.	S: n.s.
	ANL	M	13,0	12,6	7,6	6,4	B: 7.739***				B: 8.563**			
		SD	9,9	10,0	9,4	8,4	W: 46.802**	D***	D: n.s.	D***	W: 74.342***	D***	D***	D***
		Range	-7-34	-8-35	-5-41	-6-33		S***	S: n.s.	S***		S***	S: n.s.	S***
Condition 2: Running speech and ANL babble	**MCL**	M	63,0	64,2	65,3	65,3								
		SD	9,0	9,7	12,3	11,3								
		Range	41-78	43-97	37-89	37-85								
	BNL	M	46,5	48,0	54,4	54,7								
		SD	9,8	10,8	14,4	14,1								
		Range	25-75	23-83	18-83	22-79								
	ANL	M	16,6	16,2	10,9	10,6								
		SD	10,2	9,3	8,0	7,7								
		Range	-1-35	-1-37	1-34	2-32								
Condition 3: ISTS as speech and Dantale noise	**MCL**	M	62,7	61,8	63,2	63,5								
		SD	9,1	9,5	10,4	10,1								
		Range	37-87	37-93	38-82	38-80								
	BNL	M	51,2	51,9	56,5	57,9								
		SD	9,5	11,0	12,8	12,9								
		Range	31-80	33-91	26-87	27-86								
	ANL	M	11,6	9,9	6,8	5,6								
		SD	7,7	8,3	7,6	6,9								
		Range	-1-27	-9-31	-7-31	-6-23								

Table IV. Mean (M) and standard deviation (SD) of MCL, BNL, and ANL for the female and male subjects in Danish and Swedish populations for the three test conditions. Ranges have been omitted to increase readability.

			Danish females (n=24)		**Danish males (n=16)**		**Swedish females (n=31)**		**Swedish males (n=9)**	
			Right ear	**Left ear**	**Right ear**	**Left ear**	**Right ear**	**Left ear**	**Right ear**	**Left ear**
Condition 1:	**MCL**	M	64,3	64,4	62,6	63,5	65,3	64,8	64,2	64,1
Running speech and Dantale noise		SD	10,2	11,0	7,4	8,5	10,9	10,5	14,4	15,7
	BNL	M	51,1	52,0	49,9	50,6	56,7	57,8	59,7	59,7
		SD	11,0	12,2	9,6	11,6	13,5	13,9	18,5	18,4
	ANL	M	13,2	12,4	12,8	12,9	8,5	7,0	4,5	4,4
		SD	9,8	9,7	10,3	10,7	10,2	9,2	5,1	5,0
Condition 2:	**MCL**	M	63,2	64,1	62,9	64,3	65,3	65,5	64,9	64,8
Running speech and ANL babble		SD	9,5	10,6	8,4	8,6	11,1	9,7	16,6	16,2
	BNL	M	46,7	48,1	46,2	47,9	53,7	54,0	56,9	57,1
		SD	9,8	10,7	10,0	11,3	12,4	12,8	20,6	18,7
	ANL	M	16,5	16,1	16,7	16,3	11,7	11,5	8,0	7,6
		SD	9,8	8,3	11,2	10,9	8,5	8,4	4,7	4,0
Condition 3:	**MCL**	M	63,0	61,4	62,4	62,3	63,3	63,9	63,1	62,2
ISTS as speech and Dantale noise		SD	10,0	10,5	7,9	8,2	9,4	9,3	14,0	13,2
	BNL	M	51,8	52,1	50,1	51,5	55,8	57,6	58,8	58,6
		SD	10,6	11,4	7,8	10,6	11,2	11,8	18,1	16,9
	ANL	M	11,1	9,3	12,3	10,8	7,5	6,2	4,4	3,6
		SD	8,1	8,1	7,3	8,8	8,1	7,3	5,7	5,4

Table V. Single measure intraclass correlation coefficients for trials within each test condition and ear for both Danish (n=40) and Swedish subjects (n=40).

			Danish subjects (n=40)			Swedish subjects (n=40)		
	Trials compared	**Ear**	**Correlation coefficient**	**Confidence intervals**	**Significance**	**Correlation coefficient**	**Confidence intervals**	**Significance (p-value)**
Condition 1: Running speech and Dantale noise	**MCL**	R	0.918	0.867-0.953	<0.001	0.933	0.891-0.962	<0.001
		L	0.920	0.869-0.954	<0.001	0.944	0.907-0.968	<0.001
	BNL	R	0.931	0.887-0.960	<0.001	0.949	0.916-0.971	<0.001
		L	0.947	0.913-0.970	<0.001	0.961	0.936-0.978	<0.001
	ANL	R	0.945	0.909-0.969	<0.001	0.941	0.903-0.966	<0.001
		L	0.943	0.906-0.967	<0.001	0.941	0.903-0.966	<0.001
Condition 2: Running speech and ANL babble	**MCL**	R	0.940	0.901-0.966	<0.001	0.948	0.914-0.970	<0.001
		L	0.950	0.918-0.972	<0.001	0.940	0.901-0.965	<0.001
	BNL	R	0.922	0.873-0.955	<0.001	0.944	0.907-0.968	<0.001
		L	0.934	0.891-0.962	<0.001	0.947	0.913-0.970	<0.001
	ANL	R	0.954	0.924-0.974	<0.001	0.922	0.872-0.955	<0.001
		L	0.917	0.864-0.952	<0.001	0.907	0.850-0.947	<0.001
Condition 3: ISTS as speech and Dantale noise	**MCL**	R	0.930	0.886-0.960	<0.001	0.907	0.849-0.946	<0.001
		L	0.927	0.881-0.958	<0.001	0.905	0.846-0.945	<0.001
	BNL	R	0.901	0.839-0.942	<0.001	0.959	0.933-0.977	<0.001
		L	0.932	0.888-0.961	<0.001	0.920	0.869-0.954	<0.001
	ANL	R	0.916	0.863-0.952	<0.001	0.905	0.847-0.945	<0.001
		L	0.928	0.883-0.959	<0.001	0.865	0.785-0.921	<0.001

Legends

Table I. Demographic data for all subjects (n=80).

Table II. The average RMS-values for the test signals measured on the electrical output. The dB-reference indicates maximum level on sound card.

Table III. Mean, standard deviation, and ranges of MCL, BNL, and ANL for the Danish (D) and Swedish (S) subjects for the three test conditions. F-values show the between (B) population effects and within (W) population main effects. Significant effects were post hoc analysed and significant ones are shown as ** ($p < 0.01$) or *** ($p < 0.001$) at given condition.

Table IV. Mean (M) and standard deviation (SD) of MCL, BNL, and ANL for the female and male subjects in Danish and Swedish populations for the three test conditions. Ranges have been omitted to increase readability.

Table V. Single measure intraclass correlation coefficients for trials within each test condition and ear for both Danish (n=40) and Swedish subjects (n=40).

Figure 1. The long-term envelope spectra (Digital Fourier Transform using 256 points and Blackmann window) for the speech signals and noises used.

Figure 2a. Box plots for MCL in the three test conditions for the Danish (n=40) and Swedish subjects (n=40). Boxes represent interquartile ranges (IQRs), straight lines within boxes show medians and error bars represent Tukey's hinges, i.e. the highest and lowest values that are not defined outliers or extreme values. Circles indicate outliers, i.e. values that are more than 1.5 IQRs but less than 3.0 IQRs from the end of a box. Stars indicate extreme values that lay more than 3.0 IQRs from the end of a box.

Figure 2b. Box plots for BNL in the three test conditions for the Danish (n=40) and Swedish subjects (n=40). Boxes represent interquartile ranges (IQRs), straight lines within boxes show medians and error bars represent Tukey's hinges, i.e. the highest and lowest values that are not defined outliers or extreme values. Circles indicate outliers, i.e. values that are more than 1.5 IQRs but less than 3.0 IQRs from the end of a box. Stars indicate extreme values that lay more than 3.0 IQRs from the end of a box.

Figure 2c. Box plots for ANL in the three test conditions for the Danish (n=40) and Swedish subjects (n=40). Boxes represent interquartile ranges (IQRs), straight lines within boxes show medians and error bars represent Tukey's hinges, i.e. the highest and lowest values that are not defined outliers or extreme values. Circles indicate outliers, i.e. values that are more than 1.5 IQRs but less than 3.0 IQRs from the end of a box. Stars indicate extreme values that lay more than 3.0 IQRs from the end of a box.

Figure 3. The linear associations between the ANL results obtained in the three test conditions used; note that data for both ears are shown. Danish results are presented in the left column and the Swedish in the right column.