

Package ‘SII’

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Type Package

Title Calculate ANSI/ASA S3.5-1997 (R2024) Speech Intelligibility Index

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Description Calculates the American National Standards Institute (ANSI) S3.5-1997 Speech Intelligibility Index (SII) (ANSI, 1997), a standard method for computing the intelligibility of speech from acoustical measurements of speech, noise, and hearing thresholds. This package includes data frames corresponding to Tables 1 - 4 in the ANSI standard as well as functions utilizing these tables and user-provided hearing threshold and noise level measurements to compute the SII score. The methods implemented here extend the standard computations to allow calculation of SII when the measured frequencies do not match those required by the standard by applying interpolation. The package also includes a native C++ implementation of the 'AUDMOD' specific loudness model for impaired hearing (Bramslow, 2004), ported from the 'bramslow2004' implementation in the Auditory Modeling Toolbox (AMT), to calculate loudness in sones. It provides methods to predict aided SII under hearing aid prescriptive rationales, including Open-NL (Open Non-Linear), a theoretical optimization framework that uses a Nelder-Mead simplex search to maximize the SII (by default with the Johnson and Dillon (2011) desensitization correction), subject to loudness penalties and simulated Maximum Power Output (MPO) constraints. Further functions calculate real-ear insertion gains, estimate maximum power output (SSPL90), and prescribe dynamic range compression. Open-NL and the prescription functions are research tools for theoretical modeling and simulation; they have not been clinically validated and are not intended for fitting hearing aids to patients. Development of this package was originally funded by the Center for Bioscience Education and Technology (CBET) of the Rochester Institute of Technology (RIT).

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SII-package	<i>Calculate ANSI/ASA S3.5-1997 (R2024) Speech Intelligibility Index</i>
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Description

This package calculates ANSI/ASA S3.5-1997 (R2024) Speech Intelligibility Index (SII), a standard method for computing the intelligibility of speech from acoustical measurements of speech, noise, and hearing thresholds. This package includes data frames corresponding to Tables 1 - 4 in the ANSI standard as well as a function utilizing these tables and user-provided hearing threshold and noise level measurements to compute the SII score. The methods implemented here extend the standard computations to allow calculation of SII when the measured frequencies do not match those required by the standard by applying interpolation to obtain values for the required frequencies.

Author(s)

Gregory R. Warnes <greg@warnes.net>

References

ANSI/ASA S3.5-1997 (R2024), "American National Standard Methods for Calculation of the Speech Intelligibility Index" American National Standards Institute, New York.

Other software programs for calculating SII are available from <https://sii.to/html/programs.html>.

Examples

```
## Example C.1 from ANSI/ASA S3.5-1997 (R2024) Annex C
sii.C1 <- sii(
  speech = c(50.0, 40.0, 40.0, 30.0, 20.0, 0.0),
  noise   = c(70.0, 65.0, 45.0, 25.0, 1.0, -15.0),
  threshold= c(0.0, 0.0, 0.0, 0.0, 0.0, 0.0),
  method="octave"
)
sii.C1 # rounded to 2 digits by default
print(sii.C1$sii, digits=20) # full precision
summary(sii.C1) # full details
plot(sii.C1) # plot
## The value given in the Standard is $0.504$.
```

calculate_binaural_loudness

Calculate Psychoacoustic Binaural Loudness (Sones)

Description

Calculates the total perceived binaural loudness based on the Pieper et al. (2021) and Moore et al. (2016) binaural summation models.

Usage

```
calculate_binaural_loudness(x_left, x_right = NULL, alpha_b = -0.25)
```

Arguments

<code>x_left</code>	An object of class ‘SII’ for the left ear.
<code>x_right</code>	Optional. An object of class ‘SII’ for the right ear. If NULL, assumes a perfectly symmetric bilateral fitting (<code>x_left == x_right</code>).
<code>alpha_b</code>	Numeric. The binaural inhibition factor. Default is -0.25, reflecting classical normal-hearing binaural inhibition.

Value

A numeric value representing the total binaural loudness in Sones.

calculate_loudness	<i>Calculate Loudness (Sones)</i>
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Description

Calculates the estimated loudness in sones for a given Speech Intelligibility Index (SII) object.

Usage

```
calculate_loudness(x)
```

Arguments

x An object of class SII as returned by [sii](#).

Value

Returns a numeric value representing the total loudness in sones.

Author(s)

Mark Shaver

Examples

```
sii.res <- sii(speech=c(50, 40, 40, 30, 20, 0), threshold=rep(0,6), method="octave")
calculate_loudness(sii.res)
```

calculate_loudness_audmod

AMT 1.6.0 bramslow2004 (AUDMOD) Loudness Model

Description

This function computes the loudness of a signal using a faithful C++ port of the AMT 1.6.0 bramslow2004 model (Bramslow Nielsen 1993; Bramslow 2004, 2024).

Usage

```
calculate_loudness_audmod(
  freq,
  level_dB_per_Hz,
  audiogram_freq,
  audiogram_HL,
  ucl_HL = rep(120, 13),
  fs = 32000,
```

```

    N = 8192,
    Binaural = 0,
    ref = NULL
)

```

Arguments

freq	Frequencies of the signal spectrum.
level_dB_per_Hz	Signal spectrum levels in dB/Hz.
audiogram_freq	Audiogram frequencies (Hz).
audiogram_HL	Audiogram hearing loss (dB HL).
ucl_HL	Uncomfortable loudness levels (dB HL). Defaults to 120 dB HL at all frequencies.
fs	Sampling rate. Default is 32000.
N	FFT size. Default is 8192.
Binaural	0 for monaural, 1 for binaural.
ref	Optional reference object returned by a previous call.

Value

A list containing total loudness (Ldn), specific loudness (N_prime), fc, E_Vector, and the reference object (ref).

calculate_loudness_cpp

Calculate Canonical Loudness (Native C++ Engine)

Description

Native C++ port of the bramslow2004 canonical engine, corrected per AMToolbox 1.6.0 reference with noted simplifications.

Usage

```

calculate_loudness_cpp(
  inputF,
  inputLdB,
  HLcf,
  HLdB,
  NoChan = 30L,
  E_Beg = 3,
  E_End = 32,
  Binaural = 0L
)

```

Arguments

inputF	Vector of input frequencies (Hz)
inputLdB	Vector of input spectrum levels (dB/Hz, free field)
HLcf	Audiogram frequencies (Hz)
HLdB	Total hearing loss at audiogram frequencies (dB HL)
NoChan	Number of ERB channels (default 30)
E_Beg	Lowest ERB rate (default 3.0)
E_End	Highest ERB rate (default 32.0)
Binaural	Integer indicating whether to compute binaural loudness (default 0L)

Value

A list containing Loudness (sones), Excitation, Cams, and CFs.

critical	<i>Constants Tables for ANSI/ASA S3.5-1997 (R2024) Speech Intelligibility Index (SII)</i>
----------	---

Description

Tables of constants for ANSI/ASA S3.5-1997 (R2024) Speech Intelligibility Index (SII)

Usage

```
data(critical)
data(equal)
data(onethird)
data(octave)
data(overall.spl)
```

Format

Each data frames has 6-21 observations and a subset of the following variables:

- fi Center frequency of SII band, Hz
- li Lower limit of frequency band, Hz
- hi Upper limit of frequency band, Hz
- Deltai Band width adjustment, dB
- Ii Band importance function
- normal, raised, loud **and** shout Standard spectrum levels for vocal effort levels "normal", "raised", "loud", and "shout", respectively, dB
- Xi Spectrum level of internal noise, dB
- Fi Band importance function (weight)

Details

These data objects provide constant tables 1 – 4 from the ANSI S3.5-1997.

critical Table 1: Critical band SII procedure constants

equal Table 2:Equally contributing (17 band) critical band SII

onethird Table 3: One-third octave band SII procedure constants

octave Table 4: Octave band SII procedure constants

overall.spl Overall sound pressure level (SPL) for the for vocal effort levels "normal", "raised", "loud", and "shout", in dB

Source

ANSI/ASA S3.5-1997 (R2024), "American National Standard Methods for Calculation of the Speech Intelligibility Index" American National Standards Institute, New York.

References

ANSI/ASA S3.5-1997 (R2024), "American National Standard Methods for Calculation of the Speech Intelligibility Index" American National Standards Institute, New York.

Examples

```
data(critical)
critical # show entire table

data(equal)
names(equal)
equal$fi # extract just the frequency band centers

data(onethird)
barplot(onethird$Ii) # plot band importance function (weights)

data(octave)
round(octave, digits=2) # just 2 digits

data(overall.spl)
overall.spl
```

export_gains	<i>Export prescribed insertion gains for 50, 65, and 80 dB SPL input levels</i>
--------------	---

Description

Export prescribed insertion gains for 50, 65, and 80 dB SPL input levels

Usage

```
export_gains(x)
```

Arguments

x An object of class ‘SII’

Value

A data.frame containing frequency and the prescribed insertion gains

get_specific_loudness *Calculate Psychoacoustic Loudness (Sones)*

Description

Calculates the total perceived loudness in Sones based on the specific speech spectrum and hearing thresholds of the patient.

Usage

```
get_specific_loudness(x)
```

Arguments

x An object of class SII.

Details

The current implementation uses a first-order heuristic model of recruitment based on Stevens’ Power Law, mapped over an estimated dynamic range. While it is computationally fast and demonstrates the restoration of loudness conceptually, it is not a full psychoacoustic model (like Moore-Glasberg / CAM2Q), as it does not calculate basilar membrane excitation patterns via RoEx filters.

Mathematical Formula:

1. **Uncomfortable Loudness Level (UCL)** is predicted from the threshold (T_i):

$$UCL_i = 100 + 0.25 \times \max(0, T_i - 20)$$

2. **Dynamic Range (DR):**

$$DR_i = \max(1, UCL_i - T_i)$$

3. **Sensation Level (SL)** of speech peaks (RMS + 15 dB):

$$SL_i = \max(0, E_i + 15 - T_i)$$

4. **Loudness Level (Phons)** modeling recruitment:

$$Phons_i = \left(\frac{SL_i}{DR_i} \right) \times 100$$

5. Specific Loudness (Sones) per band via Stevens' Power Law:

$$Sones_i = 2^{\frac{Phons_i - 40}{10}} \quad \text{for } Phons_i \geq 40$$

$$Sones_i = \left(\frac{Phons_i}{40} \right)^{2.5} \quad \text{for } Phons_i < 40$$

6. Total Loudness (Sones):

$$Sones_{Total} = \sum Sones_i \times \text{calibration_factor}$$

The calibration factor (0.25 for 21 critical bands) is scaled dynamically based on the number of frequency bands used in the underlying SII method (e.g., 21 for critical, 6 for octave) to ensure equivalent loudness summation across different resolutions.

Value

A numeric value representing the total loudness in Sones.

open_nl

Open-NL WDRC Gain Prescription

Description

Calculates experimental prescriptive insertion gain and SSPL90 targets for a given hearing loss, based on a rule-based WDRC heuristic.

Usage

```
open_nl(
  speech = 65,
  threshold,
  freq,
  cap_override = NULL,
  vent_floor = -10,
  ...,
  gender = "male",
  experience = "experienced",
  config = "bilateral",
  coupling = "custom_occluded",
  module = "standard",
  ldl = NULL,
  loss = NULL,
  distortion_category = NULL,
  user_cr = NULL,
  optimize = TRUE,
  seed_noise = NULL,
```

```

    optim_method = "Nelder-Mead",
    abg_fraction = 0.75,
    enable_severe_booster = FALSE,
    booster_onset = 70,
    disable_sdlfp = FALSE,
    cap_rule = c("normal", "legacy"),
    objective_sii = c("johnson2011_desensitized", "none")
)

```

```

## S3 method for class 'prescription_target'
print(x, ...)

```

```

## S3 method for class 'prescription_target'
summary(object, ...)

```

```

## S3 method for class 'prescription_target'
plot(x, ...)

```

Arguments

speech	Input speech spectrum level at each frequency. If a single number is provided, it's assumed to be the overall broadband SPL.
threshold	Hearing threshold level at each frequency.
freq	Frequencies at which the thresholds are measured.
cap_override	Optional manual loudness cap override in sones.
vent_floor	Optional manual vent floor limit.
...	Additional arguments passed to methods.
gender	Gender of the patient ("male", "female").
experience	Hearing aid experience ("new", "experienced").
config	Fitting configuration ("unilateral", "bilateral").
coupling	Acoustic coupling ("custom_occluded", "open_dome", "tulip_dome", "double_dome", "vent_1mm_solid", etc.).
module	Fitting module ("standard", "cin").
ldl	Loudness Discomfort Levels (optional).
loss	Conductive hearing loss component (optional).
distortion_category	Distortion category ("Normal", "Low", "Moderate", "High").
user_cr	User defined compression ratio (optional).
optimize	Optimization flag.
seed_noise	Random noise for optimizer seeding.
optim_method	Optimization method.
abg_fraction	Air-bone gap fraction to compensate.
enable_severe_booster	Logical flag to enable severe-loss booster.

booster_onset	Threshold for the severe-loss booster (default: 70).
disable_sdlfp	Logical flag to disable the Slope-Dependent Low-Frequency Penalty (SD-LFP).
cap_rule	Loudness cap rule. "normal" (default) uses the normal-hearing loudness of unaided speech. "legacy" uses the PTA-based knots.
objective_sii	SII version maximized by the optimizer: "johnson2011_desensitized" (default; the Johnson & Dillon (2011) desensitization correction) or "none" (ANSI S3.5 SII).
x	Object for S3 method.
object	Object for S3 method.

Details

This experimental function generates non-linear prescriptive targets for research and modeling purposes. It is not intended for clinical use.

Value

An object of class `prescription_target`.

Author(s)

Mark Shaver

`prescribe_compression` *Prescribe Compression Settings based on Hearing Loss*

Description

Provides recommendations for compression speed (fast vs slow acting) and compression ratio/release times based on the four-frequency Pure Tone Average (PTA4).

Usage

```
prescribe_compression(freq, threshold, module = "standard")
```

Arguments

<code>freq</code>	A numeric vector of frequencies.
<code>threshold</code>	A numeric vector of hearing thresholds.
<code>module</code>	The operating module ("standard", "mhl").

Value

A list containing compression recommendations.

sic.critical	<i>Alternative ANSI/ASA S3.5-1997 (R2024) SII Transfer Function Weights</i>
--------------	---

Description

Alternative ANSI/ASA S3.5-1997 (R2024) Speech Intelligibility Index (SII) transfer function weights for for various types of speech material.

Usage

```
data(sic.critical)
data(sic.onethird)
data(sic.octave)
```

Format

Each data frame contains the following 8 variables, each corresponding the the transfer function weights for a specific type of speech material:

- fi Center frequency, Hz
- SII Standard SII transfer function (weights)
- NNS NNS (various nonsense syllable tests where most of the English phonemes occur equally often)
- CID22 CID-W22 (PB-words)
- NU6 NU6 monosyllables
- DRT DRT (Diagnostic Rhyme Test)
- ShortPassage short passages of easy reading material
- SPIN SPIN monosyllables
- CST Connected Speech Test

Details

- sic.critical provides alternative weights for the critical band SII procedure.
- sic.onethird provides alternative weights for the one-third octave frequency band SII procedure.
- octave provides alternative weights for the octave frequency band SII procedure.

note

There is no table of alternative weights for the equally-weighted SII band procedure as the weights for this method are (by definition) constant across all bands.

Source

All values except the CST columns are from:

ANSI/ASA S3.5-1997 (R2024), "American National Standard Methods for Calculation of the Speech Intelligibility Index" American National Standards Institute, New York.

Values in the CST columns are from the original Connected Speech Test (CST) dataset.

References

ANSI/ASA S3.5-1997 (R2024), "American National Standard Methods for Calculation of the Speech Intelligibility Index" American National Standards Institute, New York.

Examples

```
## Load the alternative weights for the critical band method
data(sic.critical)

## display the weights
round(sic.critical,3)

## draw a comparison plot
ngroup <- ncol(sic.critical)
matplot(x=sic.critical[,1], y=sic.critical[,-1],
        type="o",
        xlab="Frequency, Hz",
        ylab="Weight",
        log="x",
        lty=1:ngroup,
        col=rainbow(ngroup)
)
legend(
  "topright",
  legend=names(sic.critical)[-1],
  pch=as.character(1:ngroup),
  lty=1:ngroup,
  col=rainbow(ngroup)
)

data(onethird)
data(octave)
```

 sii

Compute ANSI/ASA S3.5-1997 (R2024) Speech Intelligibility Index (SII)

Description

Compute the Speech Intelligibility Index (SII) described by ANSI specification S3.5-1997, including extensions for conductive hearing loss. Optionally apply interpolation obtain values for the required frequencies.

Usage

```

sii(speech = c("normal", "raised", "loud", "shout"),
    noise, threshold, loss, freq,
    method = c("critical", "equal-contributing",
               "one-third octave", "octave"),
    importance = c("SII", "NNS", "CID22", "NU6", "DRT",
                  "ShortPassage", "SPIN", "CST"),
    interpolate=FALSE,
    prescription=NULL,
    desensitization=FALSE,
    ldl=NULL,
    gender="male",
    experience="experienced",
    config="bilateral",
    coupling="custom_occluded",
    module="standard",
    transducer="inserts",
    custom_gain=NULL,
    measured_wrs=NULL,
    wrs_level=NULL,
    distortion_category=NULL,
    nal_ldf=FALSE, ...)
## S3 method for class 'SII'
print(x, digits=3, ...)
## S3 method for class 'SII'
plot(x, clinical=FALSE, legend=TRUE, legend_only=FALSE, ...)
## S3 method for class 'SII'
summary(object, digits=2, ...)

```

Arguments

speech	Either a numeric vector providing E'_i , the equivalent speech spectrum level (in dB) at each frequency, or a character string indicating the stated vocal effort corresponding to one of the standard standard speech spectrum levels ("normal", "raised", "loud", "shout"). Defaults to speech="normal" corresponding to the normal level of stated vocal effort.
noise	A numeric vector providing N'_i , the equivalent noise spectrum level (in dB) at each frequency. If missing, defaults to -50 dB for each frequency.
threshold	A numeric vector providing T'_i , the equivalent hearing threshold level (in dB) at each frequency. If missing, defaults to 0 dB for each frequency.
loss	A numeric vector providing J'_i , the conductive hearing loss level (in dB) at each frequency. If missing, defaults to 0 dB for each frequency.
freq	Vector of frequencies for which speech, noise, threshold, and/or loss are specified. If interpolate=TRUE, freq must be specified. Otherwise, it must either match the required value for SII calculation method given by argument method, or be missing, in which case it will default to the values required for the specified method.

method	A character string specifying the SII calculation method ("critical", "one-third octave", "equal-contributing", "octave")
importance	Either a numeric vector providing F_i , the transfer function (importance weights) at each frequency, or a character string indicating which transfer function to employ ("SII", "NNS", "CID22", "NU6", "DRT", "ShortPassage", "SPIN", "CST"). Defaults to the standard SII transfer function, importance="SII".
interpolate	Logical flag indicating whether to interpolate from the provide measurement values and frequencies to those required by the specified method via linear interpolation on the log scale.
prescription	A character string (e.g. "NAL-R", "Open-NL"). If provided, the function will automatically calculate hearing aid insertion gain based on the specified prescriptive fitting rationale and add it to the speech and noise spectrum, calculating an Aided SII.
desensitization	Hearing loss desensitization applied to band audibility. One of "none" (standard ANSI S3.5 calculation) or "johnson2011_desensitized" (the complete Johnson and Dillon (2011) correction, computed from the sensorineural component of the threshold). For backward compatibility FALSE is treated as "none" and TRUE as "johnson2011_desensitized". Defaults to FALSE. Any other value is an error.
ldl	Numeric vector specifying Loudness Discomfort Levels (LDL) in dB HL for each frequency. If NULL, limits are estimated based on hearing thresholds.
gender	Character string specifying patient gender ("male" or "female"). Used for prescriptive algorithms. Defaults to "male".
experience	Character string specifying user hearing aid experience ("experienced", "new"). Defaults to "experienced".
config	Character string for fitting configuration ("unilateral", "bilateral"). Bilateral fittings prescribe slightly less gain (~3 dB) to account for binaural loudness summation.
coupling	Character string specifying the acoustic coupling / vent ("custom_occluded", "double_dome", "tulip_dome", "open_dome", "vent_1mm_solid", "vent_2mm_solid", "vent_3mm_solid", "vent_1mm_hollow", "vent_2mm_hollow", "vent_3mm_hollow"). Modifies low-frequency leakage and insertion gain targets.
module	Character string for hearing aid module ("standard" or other specific module constraints).
transducer	Character string specifying the audiometric transducer used for testing ("inserts" or "supra_aural"). Determines RETSPL and RECD corrections for SPLogram plots.
custom_gain	Numeric vector specifying a custom insertion gain array (in dB) for each frequency. If provided along with prescription="Custom", this gain is explicitly applied.
measured_wrs	Numeric value specifying the clinical Word Recognition Score (WRS) in percent (0-100). When provided, invokes the Margolis (2025) speech distortion model.
wrs_level	Numeric value specifying the presentation level (in dB HL or SPL) of the clinical WRS test.

<code>distortion_category</code>	Character string ("Mild", "Moderate", or "Severe") specifying the degree of speech distortion. If NULL, it is estimated based on <code>measured_wrs</code> and <code>wrs_level</code> .
<code>nal_ldf</code>	Logical flag indicating whether to use NAL-NL2 loudness discomfort factors (optional).
<code>object</code>	SII object
<code>x</code>	SII object
<code>digits</code>	Number of digits to display
<code>clinical</code>	Logical flag. If TRUE, plots a patient-friendly clinical SPLogram highlighting the audible speech area. If FALSE (the default), the behavior depends on whether the object is aided or unaided. For unaided objects, it plots a diagnostic interpolation graph. For aided objects (when a prescription was used), it automatically generates a 3-line Insertion Gain plot for 55, 65, and 75 dB SPL input levels (dynamically loading and scaling the true Normal and Loud LTASS spectra).
<code>legend</code>	Logical flag. If TRUE (the default), draws a legend on the plot.
<code>legend_only</code>	Logical flag. If TRUE, suppresses the main plot and only draws the legend in the center of the plotting window. Useful for multi-plot layouts.
<code>...</code>	Optional arguments to <code>print</code> , <code>summary</code> , and <code>plot</code> methods

Details

American National Standard ANSI/ASA S3.5-1997 (R2024) ("Methods for Calculation of the Speech Intelligibility Index") defines a method for computing a physical measure that is highly correlated with the intelligibility of speech as evaluated by speech perception tests given a group of talkers and listeners. This measure is called the Speech Intelligibility Index, or SII. The SII is calculated from acoustical measurements of speech and noise.

The `sii` function implements ANSI/ASA S3.5-1997 (R2024) as described in the standard, without any attempt to optimize the performance. The implementation does, however, include the extension for handling conductive hearing loss from Annex A (utilizing the optional `loss` argument), and for utilizing alternative band weights (i.e. transfer function) appropriate for differing message contents (e.g. types of speech) as described in Annex B or user-specified band weights (utilizing the optional `importance` argument).

Further, this implementation provides a mechanism for interpolating/extrapolating available measurements to those required for the specified calculation procedure. When `interpolate=TRUE`, required values for speech, noise, threshold, and `loss` will be computed using linear interpolation (of the log-scaled data). In this case, missing values may be provided and will be appropriately interpolated.

Prescriptive Fitting Rationales: If the `prescription` argument is provided, the function will dynamically calculate a frequency-specific hearing aid insertion gain and apply it to the speech and noise spectrum, calculating an Aided SII. The following rationales are supported:

- "NAL-R": A classic linear fitting rationale designed by the National Acoustic Laboratories to maximize speech intelligibility for mild-to-moderate losses. Gain is a linear function of the pure-tone average (PTA) and frequency-specific thresholds.

- "Open-NL": A completely transparent, open-source non-linear fitting algorithm developed specifically for this package. It was designed to serve as an open-source alternative to proprietary modern non-linear clinical targets (such as NAL-NL2 and DSL v5.0). The algorithm calculates insertion gain using the following explicit mathematical steps:
 1. **Conductive Component Separation:** If an Air-Bone Gap is present, the purely sensorineural component is isolated for WDRC compression. Linear gain representing 75% of the conductive loss is added at the end (consistent with NAL-NL2/Johnson).
 2. **Dynamic Base Gain:** The base gain relies on a dynamic multiplier (ranging from 0.43 to 0.48) determined by user experience, combined with empirical NAL-R shaping constants. Severe losses receive a booster, while steep slopes receive a low-frequency penalty to avoid upward spread of masking.
 3. **Dead Region Roll-offs:** High-frequency or low-frequency dead regions trigger a steep 30 dB/octave penalty beyond the viable boundaries to prevent acoustic distortion and feedback.
 4. **Wide Dynamic Range Compression (WDRC):** A dynamic compression ratio (ranging from 1.0 to 3.0) is applied symmetrically around a 65 dB SPL pivot point. The ratio scales dynamically based on the sensorineural threshold and measured Loudness Discomfort Levels (LDLs).
 5. **Bandwidth Roll-off:** Empirical bandwidth roll-offs are applied to limit unnecessary low/high frequency amplification, with separate curves for adults vs. infants.
 6. **Acoustic Coupling:** Adjustments are applied to the low frequencies depending on the specified venting, dome type, and acoustic seal.
 7. **MPO Limits:** Output is capped by predictive NAL-SSPL90 limits, adjusting for conductive attenuation, with an absolute safety hard cap at 120 dB SPL at the cochlea and a hardware output limit of 135 dB SPL.

Value

The return value is an object of class SII, containing the following components:

<code>call</code>	Function call used to generate the SII object
<code>orig</code>	List containing original (pre-extrapolation) values for freq, speech, noise, threshold, and loss.
<code>speech, noise, threshold, loss, and freq</code>	Values used in calculations (extrapolated if necessary)
<code>unaided_speech</code>	Original speech array before applying any prescriptive gain
<code>vocal_effort</code>	String representing the stated vocal effort
<code>gain</code>	Insertion gain array added to speech and noise when a prescription is used
<code>prescription</code>	The fitting rationale used (if any)
<code>unaided_sii</code>	Calculated SII value before applying the prescriptive gain (if a prescription was used)
<code>table</code>	SII calculation worksheet, containing columns corresponding to both Table C.1 and C.2 in Annex C of the standard. Table columns are Fi Center frequency of SII band, Hz E'i Spectrum level of equivalent speech, dB

N'i	Spectrum level of equivalent noise, dB
T'i	Equivalent hearing threshold level, dB
Vi	Spectrum level for self-speech masking, dB
Bi	Larger of the spectrum levels for equivalent noise and self-speech masking, dB
Ci	Slope per octave (doubling of frequency) of the upward spread of masking, dB/octave
Zi	Spectrum level for equivalent masking, dB
Xi	Spectrum level of internal noise, dB
X'i	Spectrum level of equivalent internal noise, dB
Di	Spectrum level for equivalent disturbance, dB
Ui	Spectrum level of standard speech for normal vocal effort, dB
Ji	Equivalent hearing threshold due to conductive hearing loss, dB
Li	Speech level distortion factor, dB
Ki	Temporary variable used in the calculation of the band audibility function
Ai	Band audibility function
Ii	Band importance function
IiAi	Product of the band importance function (Ii), and band audibility function(Ai)
sii	Calculated SII value

Open-NL Prescription Rationale

DISCLAIMER: Open-NL is an untested, experimental fitting rationale. It is designed to mimic aspects of other generic non-linear fitting rationales (such as NAL-NL2 and DSL v5.0) strictly to promote open research, algorithmic transparency, and rapid iteration within the audiology community. It is not intended for clinical use.

When prescription = "Open-NL" is selected, the function calculates and applies this WDRC-optimized rationale to maximize the aided Speech Intelligibility Index.

The mathematical algorithm consists of:

1. **Minimal Hearing Loss (MHL) Bypass:** If module == "mhl" and $PTA_{.5,1,2,4k} \leq 25$ dB HL, WDRC is bypassed. Applies flat linear gain interpolated from $(f, G) = \{(250, 0), (500, 0), (1k, 3), (2k, 5), (4k, 5), (8k, 5)\}$ dB, with a 1.5 compression ratio for loud inputs.
2. **Base Anchor (65 dB SPL Input):** $g_{65} = \max(0, m \times HTL + C)$, where $m \in \{0.40, 0.45, 0.50\}$ depending on experience, and C interpolates arrays such as $\{-8, -1, +3, +1, 0, 0, 0, 0\}$ dB evaluated at standard audiometric frequencies.
3. **Audiometric Profile Corrections:**
 - *Steep Slope Knee:* For slopes > 30 dB/octave, penalizes the "knee" (500-1500 Hz) by up to 6 dB, and boosts frequencies ≥ 2000 Hz by up to 6 dB.
 - *Severe-Loss Booster (SLB):* Adds $\min(15, \max(0, HTL - 60) \times 0.5)$ dB. Tapered heavily in mid-frequencies and disabled in dead regions.
4. **High-Frequency Desensitization:** To prevent distortion, excess gain above a limit is compressed at a 2:1 ratio.

- $\text{Limit} = 45 + 1.0 \times \max(0, HTL - 60)$

5. Roll-offs and Dead Regions:

- *Bandwidth Roll-off*: Multiplies g_{65} . Interpolates $\{(250\text{Hz}, 0.7), (500, 1.0), \dots, (6k, 0.8), (8k, 0.5)\}$.
- *Dead Regions*: Identifies HF Dead Regions ($HTL \geq 90$ at $f \geq 1k$) and LF Dead Regions ($HTL \geq 80$ at $f \leq 1k$). Applies a 30 dB/octave penalty beyond viable boundaries ($1.7 \times f_e$ for HF, $0.57 \times f_e$ for LF).

6. Bi-directional WDRC:

- *Compression Ratio (CR)*: $CR_{base} = 1 + \max(0, HTL - 20)/40$. For $HTL > 65$, CR reduces toward 1.0 in low frequencies. Overall bounded strictly to ≤ 1.5 for low frequencies (≤ 500 Hz) and up to 2.4 for high frequencies (≥ 3000 Hz).
- *Compression Threshold (CT)*: Interpolated from (HTL, CT) : $\{(20HLL, 30SPL), \dots, (100, 45)\}$.
- *Aggressive MPO Defense*: For steeply sloping losses (> 15 dB difference) with low LDLs (< 100 dB SPL), the formula proactively defends against MPO collision. The CT is aggressively lowered by up to 10 dB, and the CR is forced up by an additional 0.05 per dB of LDL penalty.
- *I/O Computation*: Calculates gain at CT (G_{CT}) scaling back from 65 dB SPL pivot. Applies linear gain below CT, and WDRC above CT.

7. Empirical Adjustments and Smoothing:

- *Demographic Boosts*: Gender: Female = -1.5 dB. Config: Unilateral = $+3.0$ dB. Experience: New users with $PTA > 40$ get up to -6.0 dB penalty.
- *LDL Dynamic Range Mapping*: If 1dl is provided, dynamic range is evaluated. For every 1 dB the measured LDL is lower than predicted, g_{65} is reduced by 0.2 dB and CR_{base} is increased by 0.02.
- *Acoustic Coupling*: Subtracts vent leakage (e.g., Open Dome = $\{-35, -28, -15, -2, 0, 0\}$ dB).
- Applies a 3-point moving average to the final gain array.

8. SSPL90 MPO Limiting:

- $MPO_{heuristic} = 100 + 0.5 \times \max(0, HTL - 40)$.
- $MPO_{safe} = LDL_{spl} - 5$.
- $PTS_{safe_limit} = 105 + 0.5 \times \max(0, HTL - 50)$.
- $MPO_{final} = \min(120, MPO_{heuristic}, MPO_{safe}, PTS_{safe_limit})$.

Author(s)

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References

ANSI/ASA S3.5-1997 (R2024), "American National Standard Methods for Calculation of the Speech Intelligibility Index" American National Standards Institute, New York.

Other software programs for calculating SII are available from <https://sii.to/html/programs.html>.

See Also

SII Constants: [critical](#), and [sic.critical](#)

Examples

```
## Example C.1 from ANSI/ASA S3.5-1997 (R2024) Annex C
sii.C1 <- sii(
  speech = c(50.0, 40.0, 40.0, 30.0, 20.0, 0.0),
  noise = c(70.0, 65.0, 45.0, 25.0, 1.0, -15.0),
  threshold= c( 0.0, 0.0, 0.0, 0.0, 0.0, 0.0),
  method="octave"
)
sii.C1 # rounded to 2 digits by default
print(sii.C1$sii, digits=20) # full precision
summary(sii.C1) # full details
plot(sii.C1) # plot
plot(sii.C1, clinical=TRUE) # clinical SPLogram plot
## The value given in the Standard is $0.504$.

## Same calculation, but manually specify the frequencies
## and importance function, and use default for threshold

sii.C1 <- sii(
  speech = c(50.0, 40.0, 40.0, 30.0, 20.0, 0.0),
  noise = c(70.0, 65.0, 45.0, 25.0, 1.0, -15.0),
  method="octave",
  freq=c(250, 500, 1000, 2000, 4000, 8000),
  importance=c(0.0617, 0.1671, 0.2373, 0.2648, 0.2142, 0.0549)
)
sii.C1

## Now perform the calculation using frequency weights for the Connected
## Speech Test (CST)
sii.CST <- sii(
  speech = c(50.0, 40.0, 40.0, 30.0, 20.0, 0.0),
  noise = c(70.0, 65.0, 45.0, 25.0, 1.0, -15.0),
  method="octave",
  importance="CST"
)
round(sii.CST$table[, -c(5:7, 13)], 2)
sii.CST$sii

## Example C.2 from ANSI/ASA S3.5-1997 (R2024) Annex C

sii.C2 <- sii(
  speech = rep(54.0, 18),
  noise = c(40.0, 30.0, 20.0, rep(0, 18-3) ),
  threshold= rep(0.0, 18),
  method="one-third"
)
sii.C2$table[1:3, 1:8]
sii.C2

## Interpolation example, for 8 frequencies using NU6 importance
```

```
## weight, default values for noise.
sii.left <- sii(
  speech="raised",
  threshold=c(25,25,30,35,45,45,55,60),
  freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
  method="critical",
  importance="NU6",
  interpolate=TRUE
)
sii.left
```

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