Calculating Speech Intelligibility Index (SII) using R

Gregory R. Warnes, Ph.D.
Gregory R. Warnes Consulting

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This document describes the calculation of Speech Intelligibility Index (SII) using R. The core calculations have been encapsulated as an R add-on package named "SII", which, once installed, can be loaded thusly:

```
> library(SII)
```

1 SII constant tables

The R package includes constant tables 1 – 4 from the ANSI S3.5-1997 text. These can be loaded via

```
> ## Table 1: Critical band SII procedure constants
> data("critical")
> head(critical)
```

```
   fi  li  hi     Ii normal raised  loud shout    Xi  Fi
1 150 100 200 0.0103  31.44  34.06 34.21 28.69   1.5 0.6
2 250 200 300 0.0261  34.75  38.98 41.55 42.50  -3.9 1.0
3 350 300 400 0.0419  34.14  38.62 43.68 47.14  -7.2 1.4
4 450 400 510 0.0577  34.58  39.84 44.08 48.46  -8.9 1.4
5 570 510 630 0.0577  33.17  39.44 45.34 50.17 -10.3 1.9
6 700 630 770 0.0577  30.64  37.99 45.22 51.68 -11.4 2.8
```

```
> ## Table 2:Equally contributing (17 band) critical band SII
> ## procedure constants
> data("equal")
> ## Table 3: One-third octave band SII procedure constants
> data("onethird")
> ## Table 4: Octave band SII procedure constants
> data("octave")
> ## Overall SPL constants
> data("overall.spl")
> overall.spl
```

```
normal raised   loud  shout
 62.35  68.34  74.85  82.30
```

It also includes constant tables for alternative transfer functions corresponding to different types of message content, tables B.1 – B.3. These tables have been augmented with the corresponding values for the Connected Speech Test (CST) as given by `http://www.sii.to/CSTdata.txt`. These tables can be loaded via:

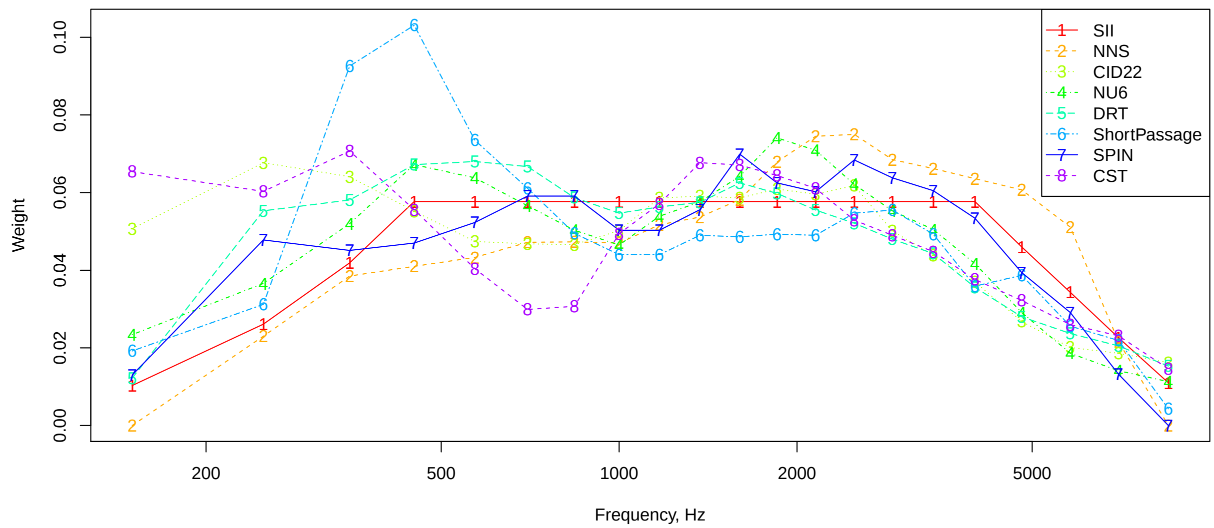
```
> ## Table B.1: Critical band importance functions for various speech tests.
> data(sic.critical)
> head(sic.critical)
```

```
   fi    SII    NNS  CID22    NU6    DRT ShortPassage   SPIN    CST
1 150 0.0103 0.0000 0.0507 0.0234 0.0122       0.0192 0.0130 0.0654
2 250 0.0261 0.0230 0.0677 0.0366 0.0553       0.0312 0.0478 0.0603
3 350 0.0419 0.0385 0.0641 0.0520 0.0581       0.0926 0.0451 0.0707
4 450 0.0577 0.0410 0.0552 0.0672 0.0672       0.1031 0.0470 0.0556
5 570 0.0577 0.0433 0.0474 0.0638 0.0680       0.0735 0.0523 0.0404
6 700 0.0577 0.0472 0.0468 0.0566 0.0667       0.0611 0.0591 0.0299
```

```
> ## Table B.2: One-third octave band importance functions for various speech tests.
> data(sic.onethird)
> ## Table B.3: Octave band importance functions for various speech tests.
> data(sic.octave)
```

With the alternative transfer functions available, it becomes easy to generate a nice graphical comparison of the functions:

```
> data(sic.critical)
> 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)
+        )
>
```



2 Calculating SII

The `sii` function implements ANSI S3.5-1997 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 argument `importance`).

Further, this implementation provides a mechanism for interpolating/extrapolating available measurements to those required for the specified procedure (via the argument `interpolate=TRUE`). Interpolation is accomplished using linear interpolation (on log-scaled data) to the frequencies required for the specified SII procedure. Interpolation is performed (if necessary) for `speech`, `noise`, `threshold`, and `loss`.

The `sii` function has the following header:

```
> args(sii)
```

```
function (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)
NULL
```

Where the arguments are:

speech Speech spectrum level, as a standard level name (”normal”, ”raised”, ”loud”, or ”shout”)or a vector of values, in dB

noise Noise spectrum level, in dB

threshold Hearing threshold level, in dB

loss Conductive hearing loss level, in dB

freq Frequencies at which values are provided (required if interpolate=TRUE)

method SII calculation method, one of "critical", "equal-contributing", "one-third octave", "octave".

importance Transfer function (importance weights), as a standard SII measurement name ("SII", "NNS", "CID22", "NU6", "DRT", "ShortPassage", "SPIN", or "CST")

interpolate Flag indicating whether to interpolate from the provide measurement values and frequencies to those required by the specified method

For a detailed description of the arguments see the `sii` manual page in appendix A.

2.1 Example C.1 from ANSI S3.5-1997 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"
+              #, importance="SII"
+              #, importance=octave$Ii
+              , importance="CST"
+              )
> round(sii.C1$table[,-c(5:7,13)],2)
```

```
    Fi E'i N'i T'i  Zi    Xi   X'i   Di    Ui   Li   Ki   Ai   Ii IiAi
1  250  50  70   0  70  -3.9  -3.9 70.0 34.75 0.97 0.00 0.00 0.09 0.00
2  500  40  65   0  65  -9.7  -9.7 65.0 34.27 1.00 0.00 0.00 0.19 0.00
3 1000  40  45   0  45 -12.5 -12.5 45.0 25.01 0.97 0.33 0.32 0.16 0.05
4 2000  30  25   0  25 -17.7 -17.7 25.0 17.32 0.98 0.67 0.66 0.30 0.20
5 4000  20   1   0   1 -25.9 -25.9  1.0  9.33 1.00 1.00 1.00 0.18 0.18
6 8000   0 -15   0 -15  -7.1  -7.1 -7.1  1.13 1.00 0.74 0.74 0.08 0.06
```

```
> sii.C1$sii
```

```
[1] 0.4873175
```

The value given in the Standard is 0.504.

2.2 Example C.2 from ANSI S3.5-1997 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]
```

```
   Fi E'i N'i T'i Vi Bi        Ci       Zi
1 160  54  40   0 30 40 -46.58708 40.00000
2 200  54  30   0 30 30 -52.00562 34.65765
3 250  54  20   0 30 30 -51.42416 25.04683
```

```
> sii.C2$sii
```

```
[1] 0.8513749
```

The standard shows the first three rows in the table as

	Fi	E'i	N'i	T'i	Vi	Bi	Ci	Zi
1	160	54.00	40.00	0.00	30.00	40.00	-46.59[1]	40.00
2	200	54.00	30.00	0.00	30.00	30.00	-52.01	34.66
3	250	54.00	20.00	0.00	30.00	30.00	-51.42	25.04

2.3 Interpolation Example

```
> 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"
+               #, importance="SII"
+               #, importance=octave$Ii
+               , importance="CST"
+               )
> round(sii.C1$table[,-c(5:7,13)],2)
```

```
    Fi E'i N'i T'i  Zi    Xi   X'i   Di    Ui   Li   Ki   Ai   Ii IiAi
1  250  50  70   0  70  -3.9  -3.9 70.0 34.75 0.97 0.00 0.00 0.09 0.00
2  500  40  65   0  65  -9.7  -9.7 65.0 34.27 1.00 0.00 0.00 0.19 0.00
3 1000  40  45   0  45 -12.5 -12.5 45.0 25.01 0.97 0.33 0.32 0.16 0.05
4 2000  30  25   0  25 -17.7 -17.7 25.0 17.32 0.98 0.67 0.66 0.30 0.20
5 4000  20   1   0   1 -25.9 -25.9  1.0  9.33 1.00 1.00 1.00 0.18 0.18
6 8000   0 -15   0 -15  -7.1  -7.1 -7.1  1.13 1.00 0.74 0.74 0.08 0.06
```

```
> sii.C1$sii
```

```
[1] 0.4873175
```

The value given in the Standard is 0.504.

2.4 Calculating SII for a set of patients

First, we need to load the patient information table

```
> library(gdata)
> patInfo <- read.xls("../AI subject list.xls")
```

Check that we got the data properly read in:

```
> ## Information about variables
> str(patInfo)
```

```
> ## First 6 rows
> head(patInfo)
```

Create some useful variables:

```
> ## measured frequencies
> freq <- c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000)
> ## columns containing frequencies for the right/left ear
> rt.cols <- paste("PTR",freq, sep="")
> lt.cols <- paste("PTL",freq, sep="")
> rt.vals <- patInfo[,rt.cols]
> lt.vals <- patInfo[,lt.cols]
```

Handle missing value encoding

```
> rt.vals[rt.vals==-888] <- NA
> lt.vals[rt.vals==-888] <- NA
```

Now, construct a utility function to handle an individual patient's SII calculation using the arguments we want.

```
> fun <- function(X)
+   {
+     ret <- try(
+               sii(X,
+                   speech="raised",
+                   threshold=c(15,15,20,25,35,35,45,50),
+                   freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
+                   importance="SII",
+                   interpolate=TRUE
+                   )$sii
+               )
+   if("try-error" %in% class(ret))
+     return(NA)
+   else
+     return(ret)
```

```
+   }
> ## Test it
> fun( rt.vals[1,] )
```

Now apply it for the right and left ears:

```
> sii.right <- apply(rt.vals, 1, fun )
> sii.left  <- apply(lt.vals, 1, fun )
```

Now add theses back onto our table:

```
> patInfo$"SII.right" <- sii.right
> patInfo$"SII.left" <- sii.left
> tail(patInfo)
```

And save to a file:

```
> write.table(patInfo,
+             file="../AI subject list-SII.xls",
+             row.names=FALSE,
+             sep="\t"
+             )
```

Now define a function to do all of this with a single call

```
> sii.dina <- function(infile, outfile, verbose=TRUE)
+   {
+     if(verbose)
+       cat("\nLoading data file '", infile, "'...\n", sep="")
+     ## Load the data
+     library(gdata)
+     patInfo <- read.xls(infile)
+
+     ## measured frequencies
+     freq <- c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000)
+
+     if(verbose)
+       cat("\nExtracting hearing thresholds...\n")
+
+     ## columns containing frequencies for the right/left ear
+     rt.cols <- paste("PTR",freq, sep="")
+     lt.cols <- paste("PTL",freq, sep="")
+
+     rt.vals <- patInfo[,rt.cols]
+     lt.vals <- patInfo[,lt.cols]
+
+     ## Handle missing code '-888'
+     rt.vals[rt.vals==-888] <- NA
+     lt.vals[rt.vals==-888] <- NA
+
```

```
+     ## define function to compute SII with our defaults
+     fun <- function(X)
+       {
+         ret <- try(
+                    sii(X,
+                        speech="raised",
+                        threshold=c(15,15,20,25,35,35,45,50),
+                        freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
+                        importance="SII",
+                        interpolate=TRUE
+                        )$sii #$
+                    )
+       if("try-error" %in% class(ret))
+         return(NA)
+       else
+         return(ret)
+       }
+
+     ## Calculate SII
+     if(verbose)
+       cat("\nCalculating right ear SII...\n")
+     sii.right <- apply(rt.vals, 1, fun )
+     if(verbose)
+       cat("\nCalculating left ear SII...\n")
+     sii.left  <- apply(lt.vals, 1, fun )
+
+     ## Add back onto the table
+     patInfo$"SII.right" <- sii.right
+     patInfo$"SII.left" <- sii.left
+
+     if(verbose)
+       cat("\nWriting new data table as '", outfile, "'...\n", sep="")
+
+     ## Save file
+     write.table(patInfo,
+                 file=outfile,
+                 row.names=FALSE,
+                 sep="\t"
+                 )
+
+     if(verbose)
+       cat("\nDone.\n\n")
+   }
```

Try it out:

```
> sii.dina(infile="../AI subject list.xls",
+          outfile="../AI subject list-SII.xls")
```

Just for kicks, compare the original AI, and our computed sii values:

```
> library(xtable)
> xt <- xtable(patInfo[,c("AI","SII.right","SII.left")],
```

```
+              caption="Comparison of original AI and new right and left SII values \\label{table}",
+              digits=2)
> print(xt)


> ## put histograms on the diagonal
> panel.hist <- function(x, ...)
+   {
+     usr <- par("usr"); on.exit(par(usr))
+     par(usr = c(usr[1:2], 0, 1.5) )
+     h <- hist(x, plot = FALSE)
+     breaks <- h$breaks; nB <- length(breaks)
+     y <- h$counts; y <- y/max(y)
+     rect(breaks[-nB], 0, breaks[-1], y, col="cyan", ...)
+   }
> pairs.2 <- function(x)
+   pairs(x,
+       panel=panel.smooth,
+       cex = 1.5,
+       pch = 24,
+       bg="light blue",
+       diag.panel=panel.hist,
+       cex.labels = 2,
+       font.labels=2
+       )
> pairs.2(patInfo[,c("AI","SII.right","SII.left")])
```

A SII Help Pages

`SII-package` *Calculate ANSI S3.5-1997 Speech Intelligibility Index*

Description

This package calculates ANSI S3.5-1997 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 S3.5-1997, "American National Standard Methods for Calculation of the Speech Intelligibility Index" American National Stan- dards Institute, New York.

Other software programs for calculating SII are available from `http://www.sii.to/html/programs.html`.

Examples

```
## Example C.1 from ANSI S3.5-1997 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 $0.504$.
```

Description

Tables of constants for ANSI S3.5-1997 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 S3.5-1997, "American National Standard Methods for Calculation of the Speech Intelligibility Index" American National Standards Institute, New York.

References

ANSI S3.5-1997, "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
```

Description

Alternative ANSI S3.5-1997 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 phonems 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.threeoctave` 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 S3.5-1997, "American National Standard Methods for Calculation of the Speech Intelligibility Index" American National Standards Institute, New York.

Values in the CST columns are from: http://www.sii.to/CSTdata.txt

References

ANSI S3.5-1997, "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(threeoctave)
data(octave)
```

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)
## S3 method for class 'SII'
print(x, digits=3, ...)
## S3 method for class 'SII'
plot(x, ...)
## 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"` correspoding 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.
`object,x`	SII object
`digits`	Number of digits to display
`...`	Optional arguments to `print`, `summary`, and `plot` methods

Details

American National Standard ANSI S3.5-1997 ("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 S3.5-1997 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 argument `importance`).

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.

Value

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

`call`	Function call used to generate the SII object
`orig`	List containing original (pre-extrapolation) values for `freq`, `speech`, `noise`, `threshold`, and `loss`.
`speech, noise, threshold, loss, and freq`	Values used in calculations (extrapolated if necessary)
`table`	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 specrum 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 auditability function
Ai Band auditability function
Ii Band importance function
IiAi Product of the band importance function (Ii), and band auditability function(Ai)

`sii` Calculated SII value

Author(s)

Gregory R. Warnes `<greg@warnes.net>`

References

ANSI S3.5-1997, "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 `http://www.sii.to/html/programs.html`.

See Also

SII Constants: `critical`, and `sic.critical`

Examples

```
## Example C.1 from ANSI S3.5-1997 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 $0.504$.



## 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 S3.5-1997 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
```

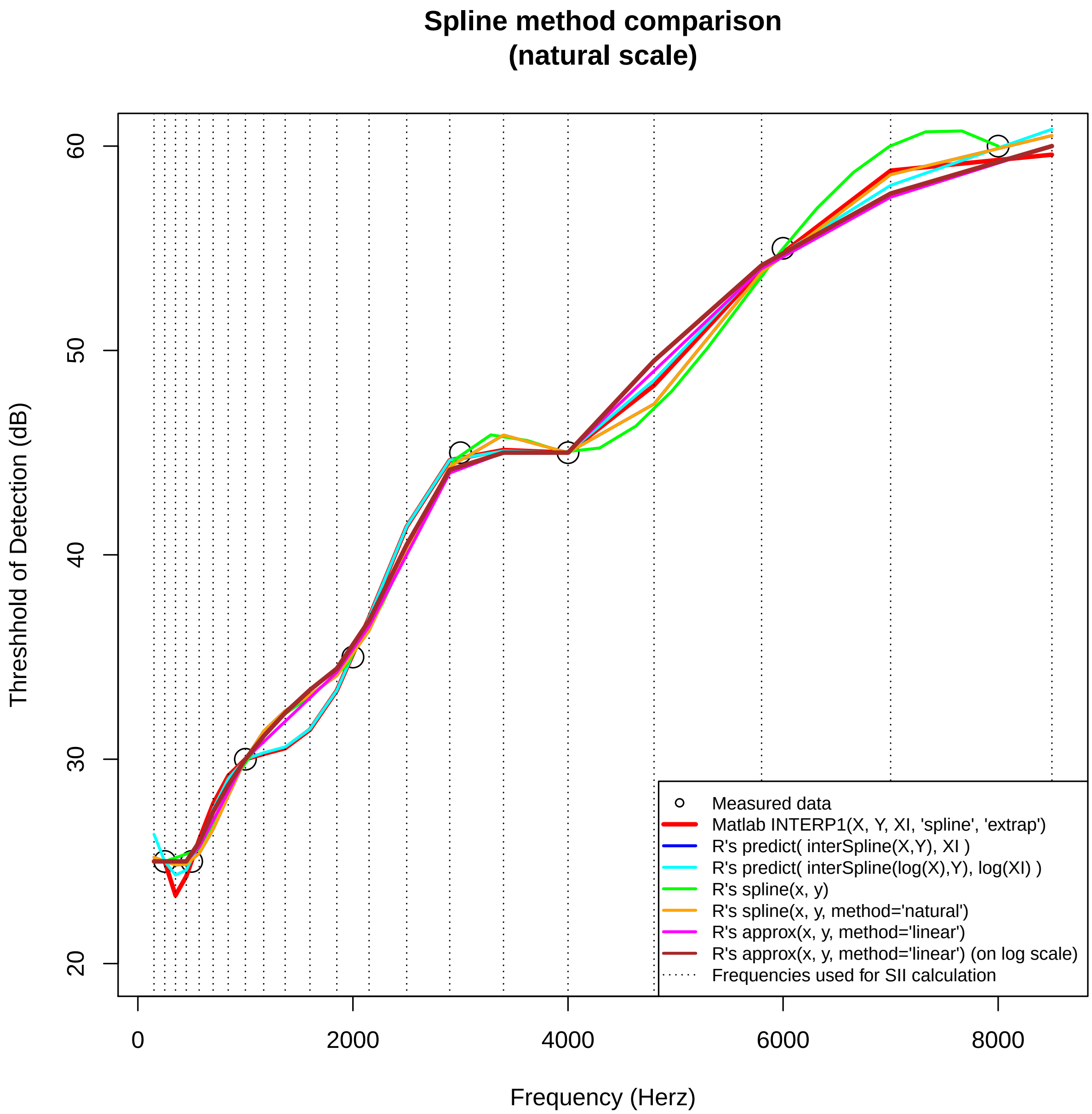
B Interpolation

Do some experimentation to determine how to best perform interpolation/extrapolation from the small set of frequencies where hearing sensitivity was measured to the set of frequencies necessary for the calculation of SII:

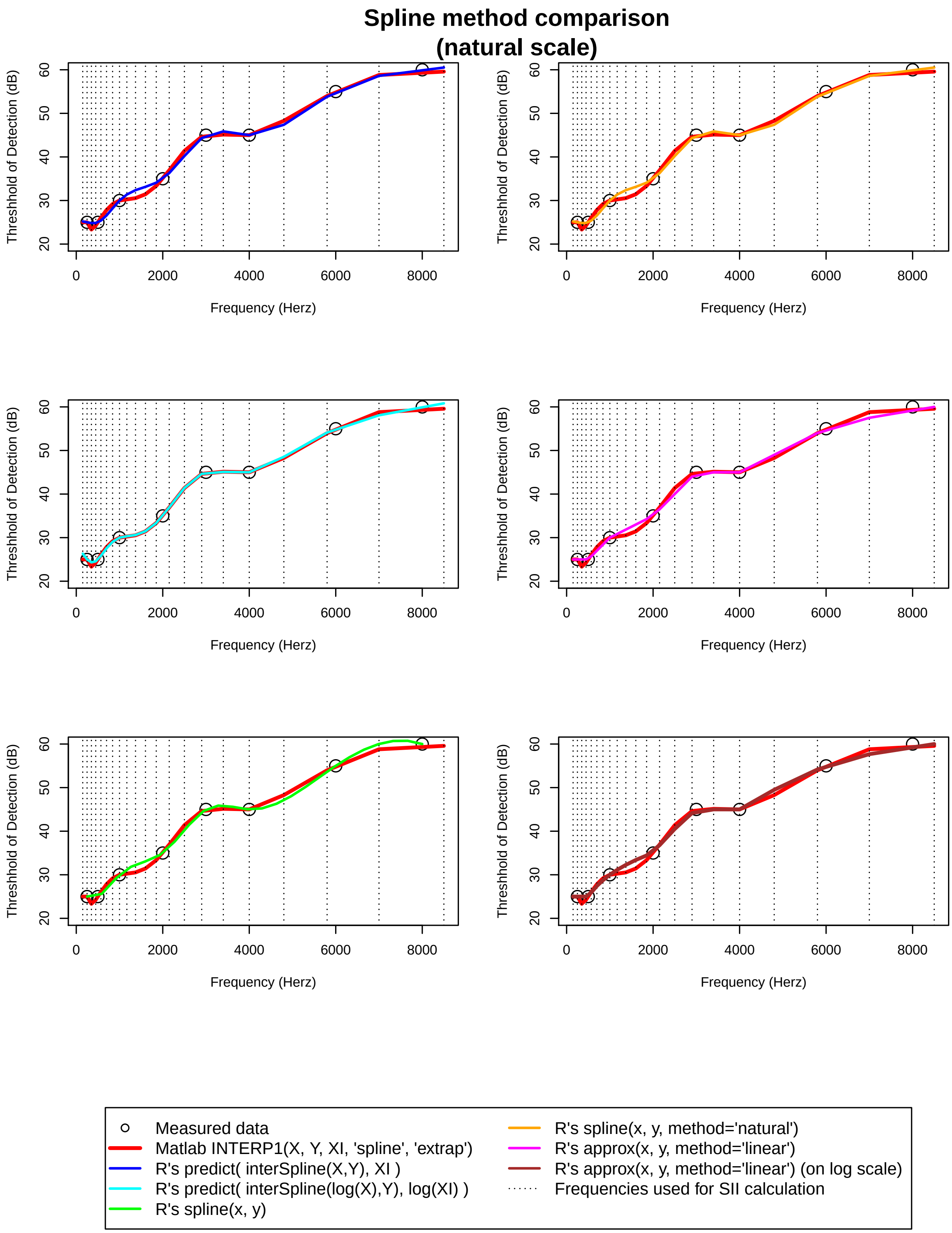
```
> THDI=c(25,25,30,35,45,45,55,60)
> freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000)
> sii.freqs <- SII:::sii.constants[,1]
> xlist <- sort(c(SII:::sii.constants[, 1], freq))
> ylist <- rep(NA, length=length(xlist))
> names(ylist) <- xlist
> ylist[ as.character(freq) ] <- THDI
```

```
> library(splines)
> ispl <- interpSpline( THDI ~ freq )
> ispl <- predict(ispl, sii.freqs)$y
> ispl.l <- interpSpline( THDI ~ log(freq) )
> ispl.l <- predict(ispl.l, log(sii.freqs) )$y
> approx.l <- function(x,y,xout,...)
+   {
+     retval <- approx(log(x), y, log(xout), ...)
+     retval$x <- xout
+     retval
+   }
>
```

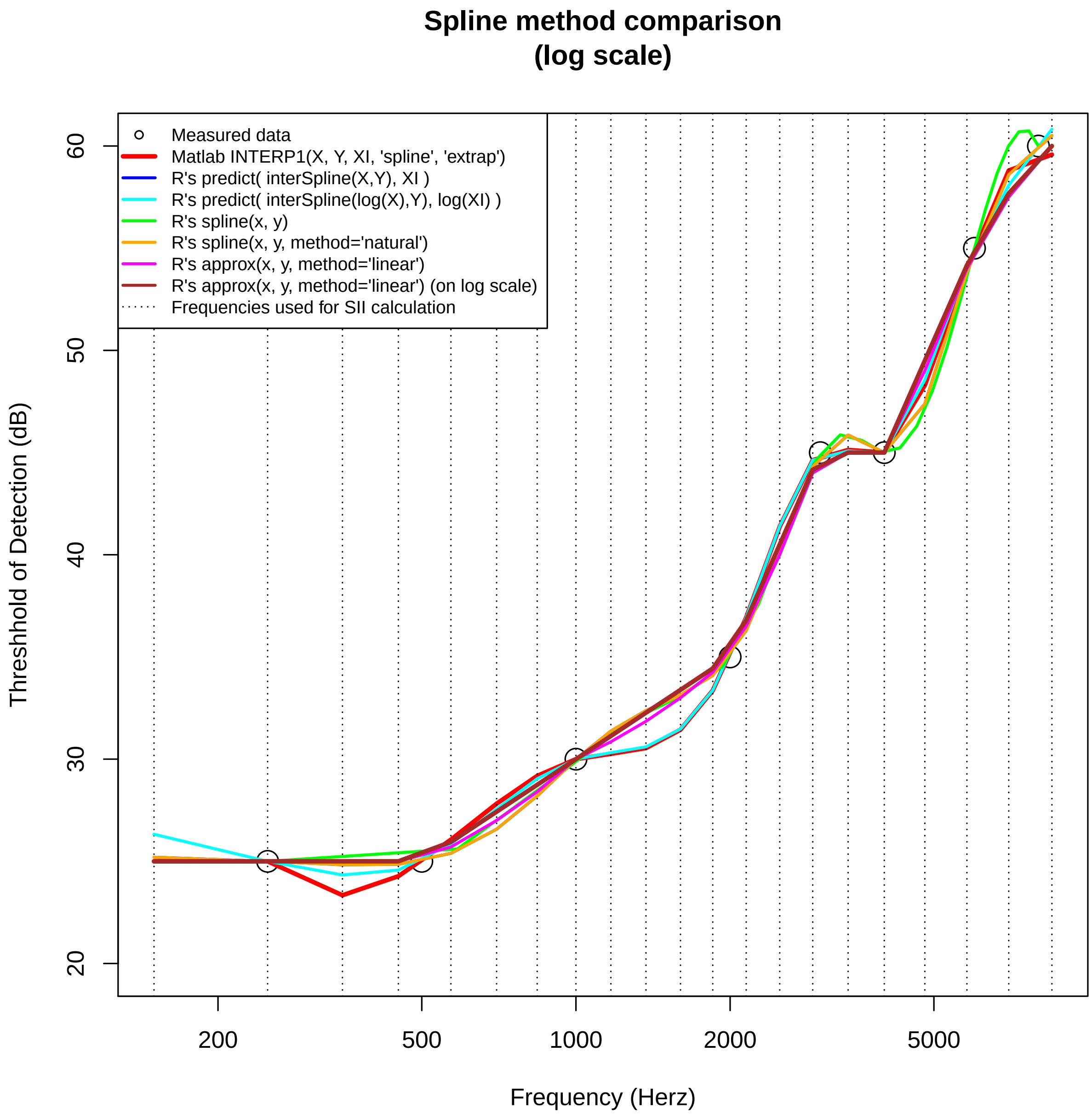
```
> doplot(FALSE, FALSE)
```



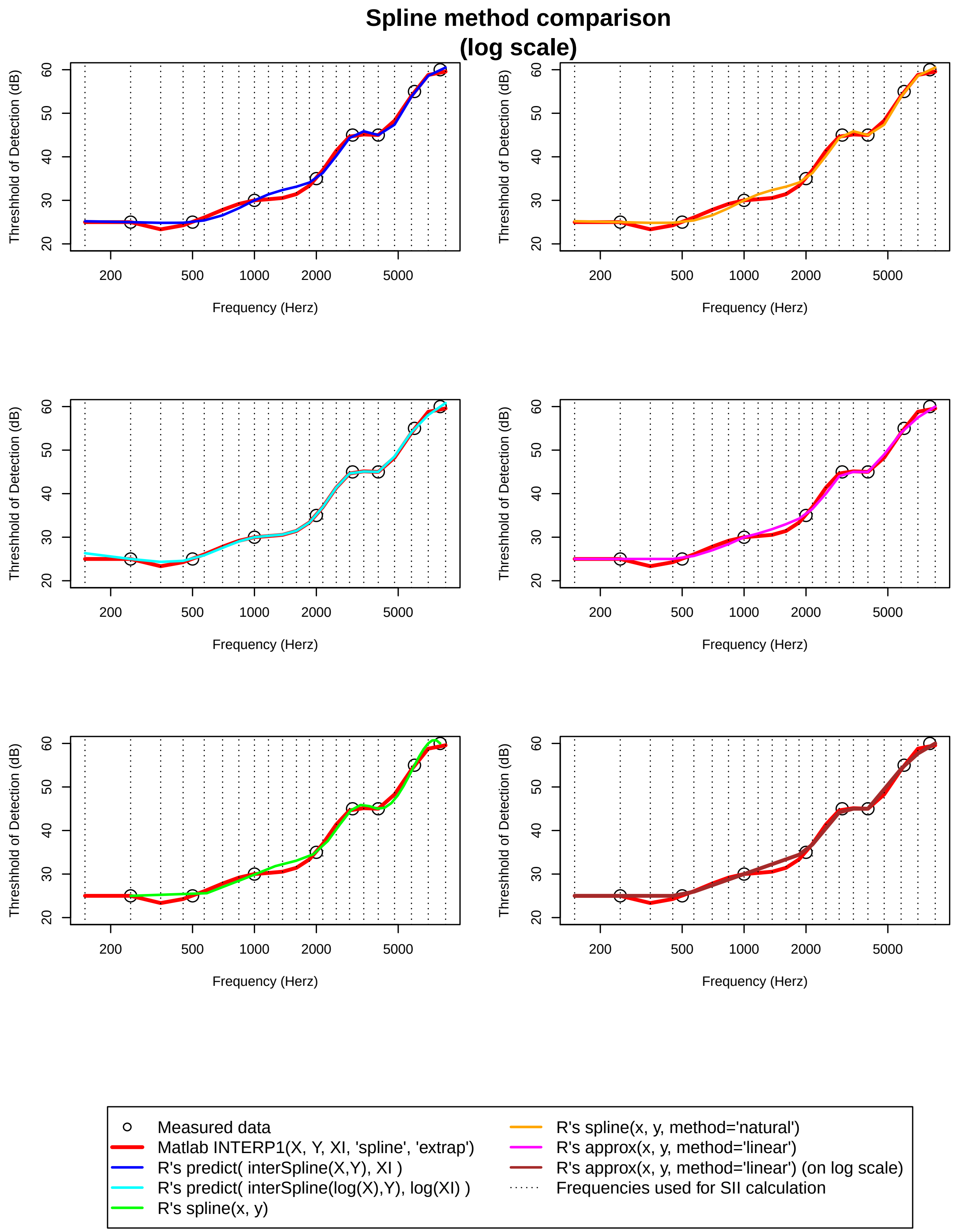

```
> doplot(FALSE, TRUE)
```


Spline method comparison
(natural scale)
Threshold of Detection (dB)
20
30
40
50
60
0
2000
4000
6000
8000
Frequency (Herz)
Measured data
Matlab INTERP1(X, Y, XI, 'spline', 'extrap')
R's predict(interSpline(X,Y), XI)
R's predict(interSpline(log(X),Y), log(XI))
R's spline(x, y)
R's spline(x, y, method='natural')
R's approx(x, y, method='linear')
R's approx(x, y, method='linear') (on log scale)
Frequencies used for SII calculation

```
> doplot(TRUE, FALSE)
```




```
> doplot(TRUE, TRUE)
```


Spline method comparison
(log scale)
Threshold of Detection (dB)
Frequency (Herz)
20
30
40
50
60
200
500
1000
2000
5000
Measured data
Matlab INTERP1(X, Y, XI, 'spline', 'extrap')
R's predict(interSpline(X,Y), XI)
R's predict(interSpline(log(X),Y), log(XI))
R's spline(x, y)
R's spline(x, y, method='natural')
R's approx(x, y, method='linear')
R's approx(x, y, method='linear') (on log scale)
Frequencies used for SII calculation

C SII function definition

C.1 Excel to R translation

First, I have defined an R function that simply translates the Excel code into R:

```
> args(SII:::sii.excel)
```

```
function (THDI, freq = c(250, 500, 1000, 2000, 3000, 4000, 6000,
    8000), matlab.spline = TRUE)
NULL
```

C.2 R code written from the ANSI S3.5-1997

Second, I implemented the SII calculation following the text of the standard. This code is more general and quite a bit more complex.

```
> args(sii)
```

```
function (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)
NULL
```

C.3 Utility functions

I also defined a utility function to nicely print the output.

```
>
```

In order to make it easy to maintain the SII contants. A single Microsoft Excel file, `\data\SII_Constants.xls` is included in the SII `data` directory containing the complete set of SII contants, where each tab corresponds to one Table from the standard.

```
> SII:::reload.constants
```

```
function (xls.path, rda.path = xls.path)
{
    if (!require("gdata"))
        stop("'gdata' package must be installed to run this function.")
    read.xls <- gdata::read.xls
    "critical" <- read.xls(xls = file.path(xls.path, "SII_Constants.xls"),
```

```
        sheet = 1, skip = 5, header = TRUE, nrows = 21, check.names = FALSE,
        row.names = 1)
    save(list = "critical", file = file.path(rda.path, "critical.rda"))
    "equal" <- read.xls(xls = file.path(xls.path, "SII_Constants.xls"),
        sheet = 2, skip = 5, header = TRUE, nrows = 17, check.names = FALSE,
        row.names = 1)
    save(list = "equal", file = file.path(rda.path, "equal.rda"))
    "onethird" <- read.xls(xls = file.path(xls.path, "SII_Constants.xls"),
        sheet = 3, skip = 5, header = TRUE, nrows = 18, check.names = FALSE,
        row.names = 1)
    save(list = "onethird", file = file.path(rda.path, "onethird.rda"))
    "octave" <- read.xls(xls = file.path(xls.path, "SII_Constants.xls"),
        sheet = 4, skip = 5, header = TRUE, nrows = 6, check.names = FALSE,
        row.names = 1)
    save(list = "octave", file = file.path(rda.path, "octave.rda"))
    "sic.critical" <- read.xls(xls = file.path(xls.path, "SII_Constants.xls"),
        sheet = 5, skip = 3, header = TRUE, nrows = 21, check.names = FALSE,
        row.names = 1)
    save(list = "sic.critical", file = file.path(rda.path, "sic.critical.rda"))
    "sic.onethird" <- read.xls(xls = file.path(xls.path, "SII_Constants.xls"),
        sheet = 6, skip = 3, header = TRUE, nrows = 18, check.names = FALSE,
        row.names = 1)
    save(list = "sic.onethird", file = file.path(rda.path, "sic.onethird.rda"))
    "sic.octave" <- read.xls(xls = file.path(xls.path, "SII_Constants.xls"),
        sheet = 7, skip = 3, header = TRUE, nrows = 6, check.names = FALSE,
        row.names = 1)
    save(list = "sic.octave", file = file.path(rda.path, "sic.octave.rda"))
    ls()
}
<bytecode: 0x55c1bbeefef0>
<environment: namespace:SII>
```

The package mainainer may use it as :

```
> SII:::reload.constants(xls.path="./SII/extdata")
```

The SII package must then be rebuilt and reinstalled for the updated contants to become available.

D Tests

D.1 Compare interpolation details for example data

D.1.1 Left Ear

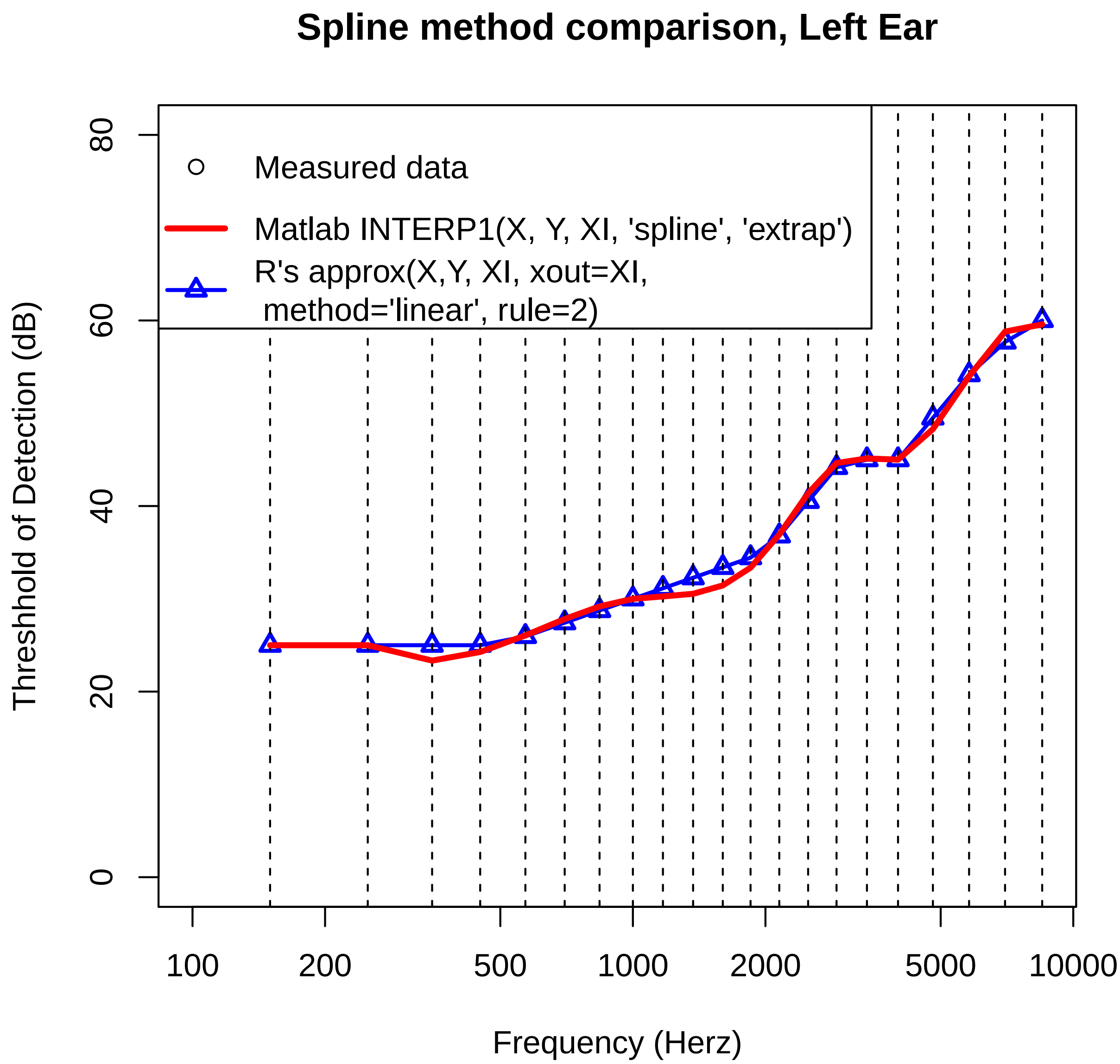
```
> sii.left <- sii(
+                 speech="raised",
+                 threshold=c(25,25,30,35,45,45,55,60),
+                 freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
+                 importance="NU6",
```

```
+                 interpolate=TRUE
+                 )
> ## comparison of our interpolation and matlab's
> tab <- cbind(
+              matlab=SII:::sii.constants[,"Ti'.THDN"],
+              R     =sii.left$table[,"T'i"],
+              delta =NA
+              )
> tab[,3] <- tab[,1] - tab[,2]
> rownames(tab) <- SII:::sii.constants[,".NFreqLin"]
> t(round(tab,2))
```

```
       150 250   350   450   570   700   840 1000  1170  1370  1600  1850  2150
matlab  25  25 23.34 24.27 26.06 27.82 29.18   30 30.26 30.54 31.44 33.36 36.93
R       25  25 25.00 25.00 25.95 27.43 28.74   30 31.13 32.27 33.39 34.44 36.78
delta    0   0 -1.66 -0.73  0.11  0.39  0.44    0 -0.87 -1.73 -1.95 -1.08  0.15
        2500  2900  3400 4000  4800  5800  7000  8500
matlab 41.38 44.63 45.13   45 48.29 53.98 58.80 59.58
R      40.50 44.16 45.00   45 49.50 54.16 57.68 60.00
delta   0.88  0.47  0.13    0 -1.21 -0.18  1.12 -0.42
```

```
> compare.plot <- function(x, matlab, title)
+   {
+     plot(x)
+     lines(SII:::sii.constants[,".NFreqLin"],
+           matlab,
+           type="l", col="red", lwd=3)
+
+     legend("topleft",
+            legend=c(
+              "Measured data",
+              "Matlab INTERP1(X, Y, XI, 'spline', 'extrap')",
+              "R's approx(X,Y, XI, xout=XI,\n method='linear', rule=2)"
+              ),
+            col=c("black", "red","blue","green","orange","magenta"),
+            pch=c(      1,    NA,    2,     NA,      NA,       NA),
+            lty=c(     NA,     1,    1,      1,       1,        1),
+            lwd=c(     NA,     3,    2,      2,       2,        2),
+            bg="white"
+            )
+     title(title)
+   }
```

```
> compare.plot(sii.left, matlab=SII:::sii.constants[, "Ti'.THDN"], title="Spline method comparison, Left
>
```



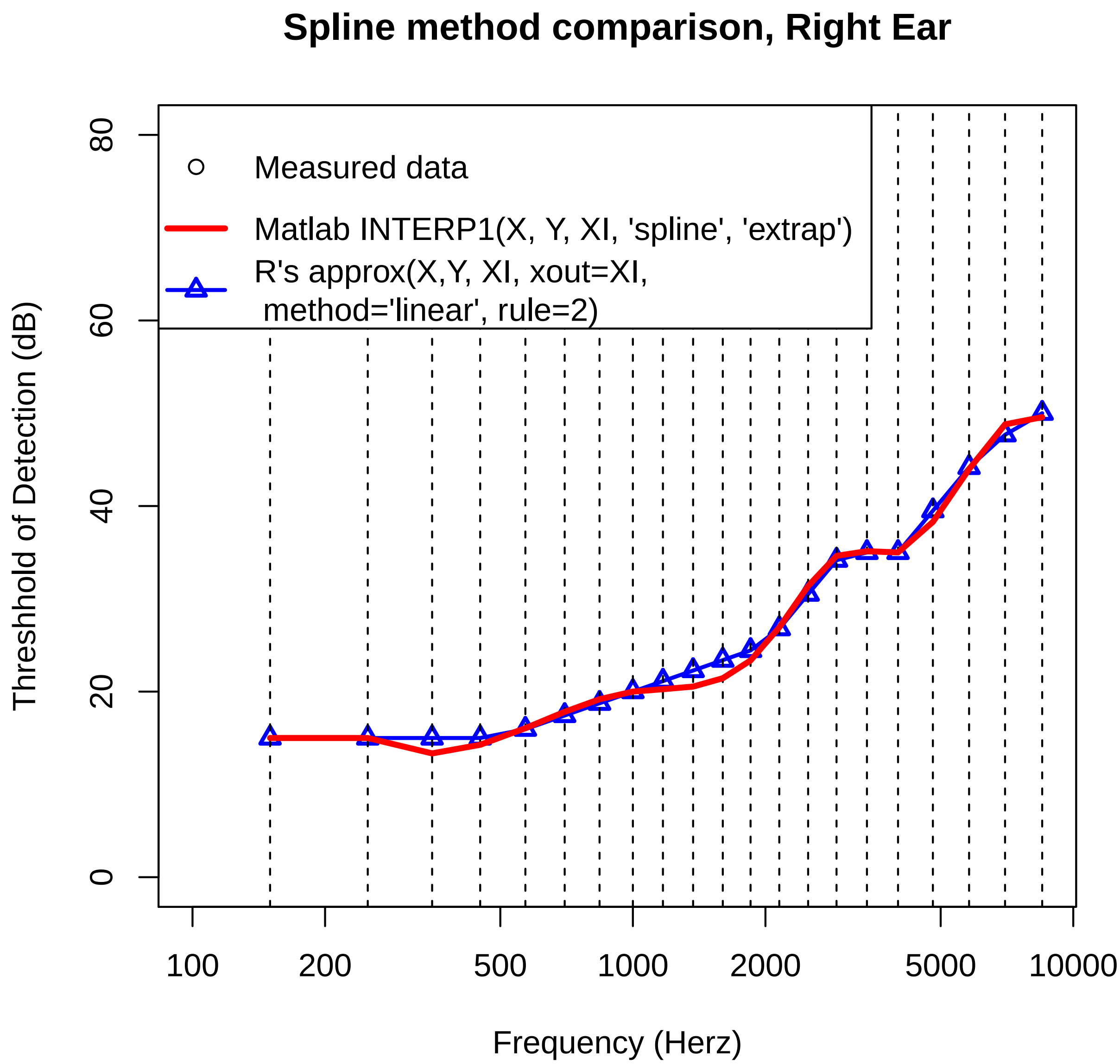
D.1.2 Right Ear

```
> # comparison of our interpolation and matlab's
>
> matlab <- c(15.00, 15.00, 13.34, 14.27, 16.06, 17.82, 19.18, 20.00,
+             20.26, 20.54, 21.44, 23.36, 26.93, 31.38, 34.63, 35.13,
+             35.00, 38.29, 43.98, 48.80, 49.58)
> sii.right <- sii(
+                  speech="raised",
+                  threshold=c(15,15,20,25,35,35,45,50),
+                  freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
+                  importance="NU6",
```

```
+                  interpolate=TRUE
+                  )
> tab <- cbind(
+              matlab=matlab,
+              R     =sii.right$table    [,"T'i"],
+              delta =NA
+              )
> tab[,3] <- tab[,1] - tab[,2]
> rownames(tab) <- SII:::sii.constants[,".NFreqLin"]
> t(round(tab,2))
```

```
       150 250   350   450   570   700   840 1000  1170  1370  1600  1850  2150
matlab  15  15 13.34 14.27 16.06 17.82 19.18   20 20.26 20.54 21.44 23.36 26.93
R       15  15 15.00 15.00 15.95 17.43 18.74   20 21.13 22.27 23.39 24.44 26.78
delta    0   0 -1.66 -0.73  0.11  0.39  0.44    0 -0.87 -1.73 -1.95 -1.08  0.15
        2500  2900  3400 4000  4800  5800  7000  8500
matlab 31.38 34.63 35.13   35 38.29 43.98 48.80 49.58
R      30.50 34.16 35.00   35 39.50 44.16 47.68 50.00
delta   0.88  0.47  0.13    0 -1.21 -0.18  1.12 -0.42
```

```
> compare.plot(sii.right, matlab=matlab, title="Spline method comparison, Right Ear")
```



D.2 Comparison with Excel implementation

Test the SII function using the example data from the Excel worksheet:

- Left ear example

  Excel code: 0.43.

  "Translated" R code:

```
> SII:::sii.excel(
+            c(25,25,30,35,45,45,55,60),
+            c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000)
+            )
```

```
SII: 0.373
```

New R code:

```
> 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),
+                 importance="NU6",
+                 interpolate=TRUE
+                 )
> sii.left
```

```
SII: 0.77
```

- Right ear example

  Excel worksheet: 0.72.

  "Translated" R code:

```
> SII:::sii.excel(
+           c(15,15,20,25,35,35,45,50),
+           c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000)
+           )
```

```
SII: 0.717
```

New R code:

```
> sii.right <- sii(
+                  speech="raised",
+                  threshold=c(15,15,20,25,35,35,45,50),
+                  freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
+                  importance="NU6",
+                  interpolate=TRUE
+                  )
> sii.right
```

```
SII: 0.906
```

- Best possible score (No detectible threshold)

  Excel Spreadsheet: 0.9887

  "Translated" R code:

```
> SII:::sii.excel(
+           rep(0,8),
+           freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000)
+           )
```

```
SII: 0.989
```

New R code:

```
> sii.best <- sii(
+                 threshold=rep(0,8),
+                 freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
+                 interpolate=TRUE
+                 )
> sii.best
```

```
SII: 0.996
```

- Worst possible score (No detectible threshold)

  Excel Spreadsheet: 0.00

  "Translated" R code:

  ```
  > SII:::sii.excel(
  +          rep(100,8),
  +          c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000)
  +          )
  ```

  ```
  SII: 0
  ```

  New R code:

  ```
  > sii.worst <- sii(
  +                 threshold=rep(100,8),
  +                 freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
  +                 interpolate=TRUE
  +                )
  > sii.worst
  ```

  ```
  SII: 0
  ```

D.3 Test handling of missing values

```
> sii.worst <- sii(
+                 threshold=c(NA, rep(100,7)),
+                 freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
+                 interpolate=TRUE
+                )
> sii.worst
```

```
SII: 0
```

```
> sii.right <- sii(
+                 speech="raised",
+                 threshold=c(0,15,15,20,25,35,35,45,50),
+                 freq=c(NA, 250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
+                 importance="NU6",
+                 interpolate=TRUE
+                 )
> sii.right
```

```
SII: 0.906
```

```
> ## This should fail, because there is no data!
> sii.NONE <- try(
+             sii(
+                 threshold=rep(NA,8),
```

```
+                  freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
+                  interpolate=TRUE
+                 )
+             )
> sii.NONE
```

```
[1] "Error in approx(x = log10(obs.freq), y = value, xout = log10(target.freq),  : \n  need at least two
attr(,"class")
[1] "try-error"
attr(,"condition")
<simpleError in approx(x = log10(obs.freq), y = value, xout = log10(target.freq),     method = "linear",
```

```
> sii.right <- sii(
+                  speech="raised",
+                  threshold=c(15,15,20,NA,35,35,45,50),
+                  freq=c(250, 500, 1000, 2000, 3000, 4000, 6000, 8000),
+                  importance="NU6",
+                  interpolate=TRUE
+                  )
> sii.right
```

```
SII: 0.895
```

```
> sii.C1.NA <- sii(
+               speech   = c(50.0, 40.0, 40.0, NA,   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,   NA,  0.0),
+               freq     = c( 250,  500, 1000, 2000, 4000, 8000),
+               method="octave",
+               importance="CST",
+               interpolate=TRUE
+               )
> sii.C1
```

```
SII: 0.487
```

```
> sii.C1.NA
```

```
SII: 0.487
```

E Final cleanup

Save the data we created here for debugging purposes:

```
> save.image("SII-Code.Rda")
```