Evaluation of a new type of hearing aid.

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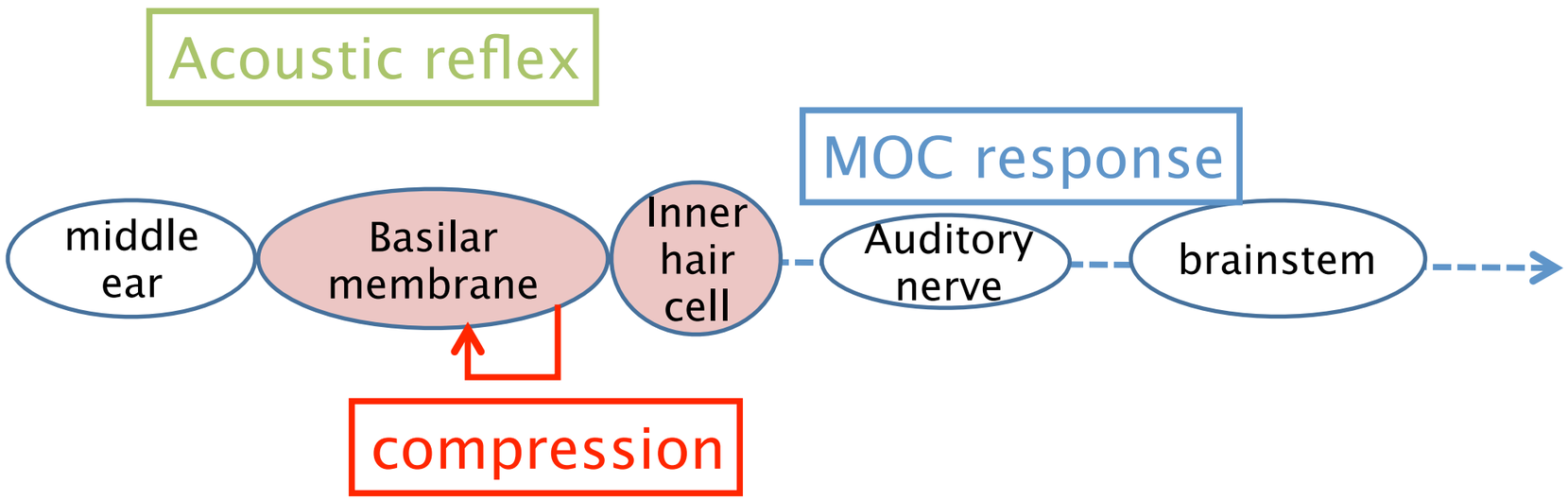
A biologically inspired hearing aid.

- The perception of loudness in normal hearing is regulated by a number of systems:
  - Medial olivocochlear (MOC) feedback system
  - Acoustic Reflex (AR)
  - Instantaneous compression at the basilar membrane
- Hearing impairment can cause failure of these systems
- A hearing aid has been developed that mimics the biology of human hearing.

The poster describes the design and preliminary testing of a biologically inspired hearing aid, the EssexAid. It aims to mimic 3 loudness-regulating systems known to be present in normal human hearing.

Level regulation in normal hearing



Basilar membrane/ Instantaneous compression

Attenuates input to inner hair cells

It has no time constant (not an AGC)

May be missing in some types of hearing impairment.

Its loss may result in 'recruitment'

MOC response

MOC works by suppressing OHC activity

It is active close to threshold

It has a moderately slow time constant (regulates sustained moderate-intensity sounds)

It may be help with speech in noise

Acoustic Reflex (AR)

AR may be active at around 70 dB SPL for **broadband** sounds.

Offers almost perfect regulation for low frequencies (1dB/1dB)

Often not recordable in impaired listeners (loss of protection)

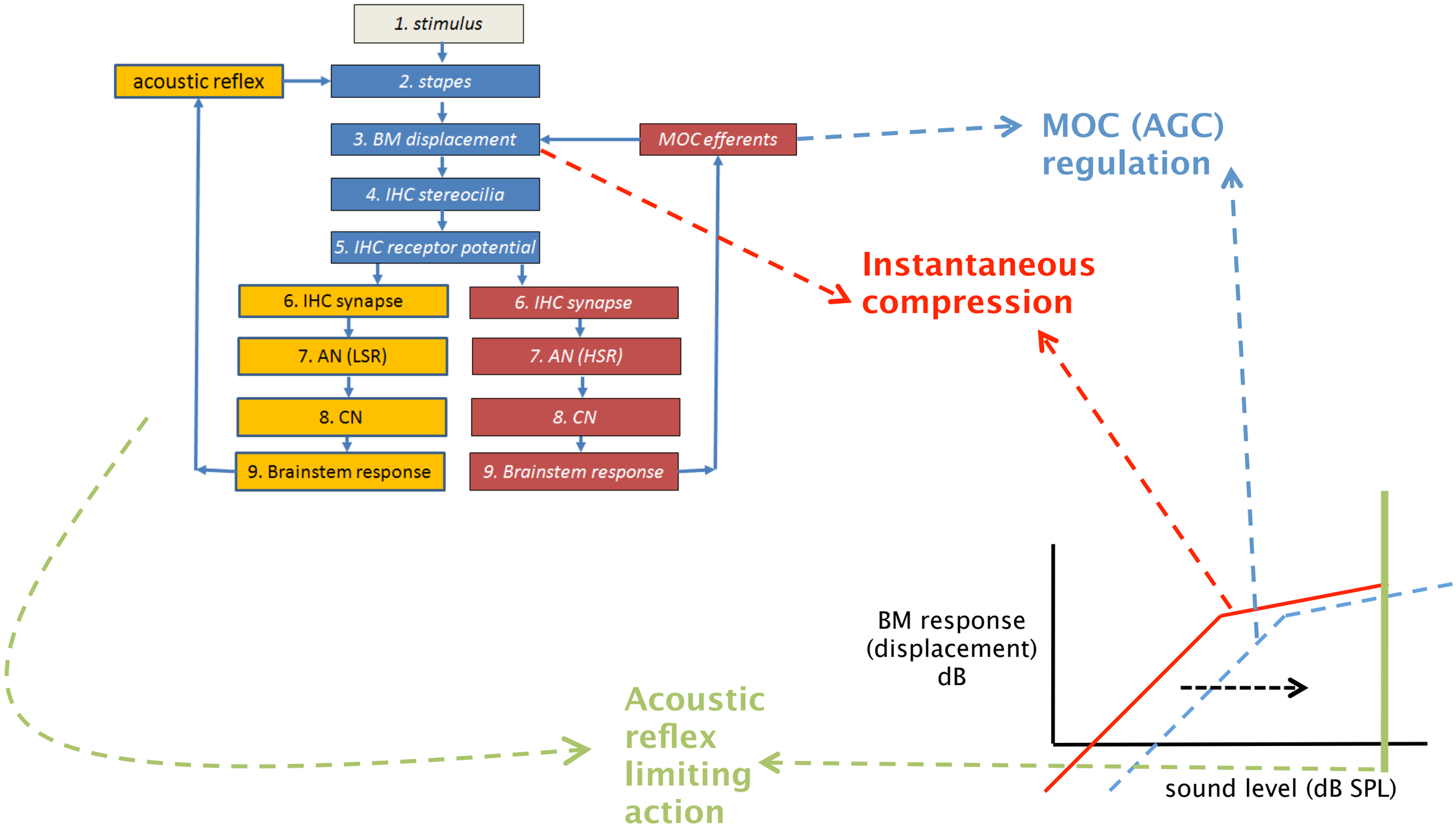
notes

Recent research has shown that the strength of response to acoustic stimulation is regulated using a number of different mechanisms. First, the mechanical response of the basilar membrane is subject to instantaneous compression. It regulates the mechanical driving force applied to the stereocilia of the inner hair cells. This compression is approximately 2 dB per 10 dB. It is not the kind of compression found in an automatic gain control (AGC) device because it has no time constant. We know that this kind of compression can be impaired in certain types of hearing impairment where it may result in recruitment, an abnormal increase in loudness as a function of signal level.

Second, there are two feedback loops that limit the response. The medial olivocochlear efferent system (MOC) suppresses the response of the basilar membrane near threshold. Basically, it changes the sensitivity of the system and is driven by moderate-intense sounds. The time constant is slow. The acoustic reflex limits the response of the stapes and has a reasonably fast time constant.

We are only beginning to understand the implications of these functions. However, it is clear that they are influencing the perceived loudness of sounds and it has also been suggested that they may contribute to our ability to hear out speech against competing acoustic backgrounds.

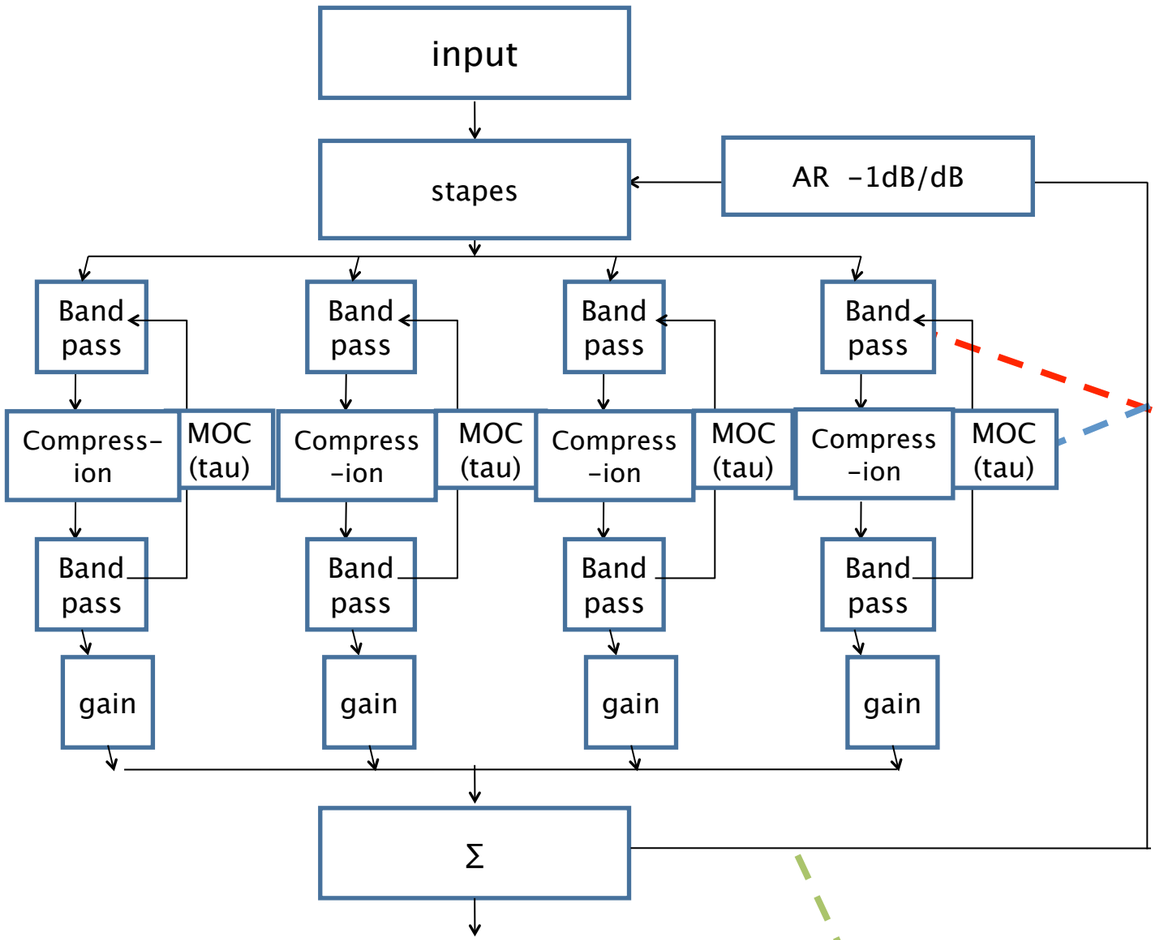
Computer model of normal hearing



notes

The EssexAid design is based on an existing computer model of normal hearing (Meddis, 2006).
The input-output function at the right illustrates how the 3 regulating functions impact on the level of a stimulus. The instantaneous compression produces an immediate reduction in level of the sound (once it has passed a specified input level, kneepoint). Animal studies have shown that the effect of MOC suppression is to shift the input output function to higher levels. In other words the level at which the instantaneous compression begins to be applied is raised. This has the effect of maintaining a region of linear response close to threshold while increasing thresholds in response to background noise. The acoustic reflex functions as a limiter at high sound levels. Although the input might increase further in level, the output of the system will show little or no increase.

Hearing aid flow diagram

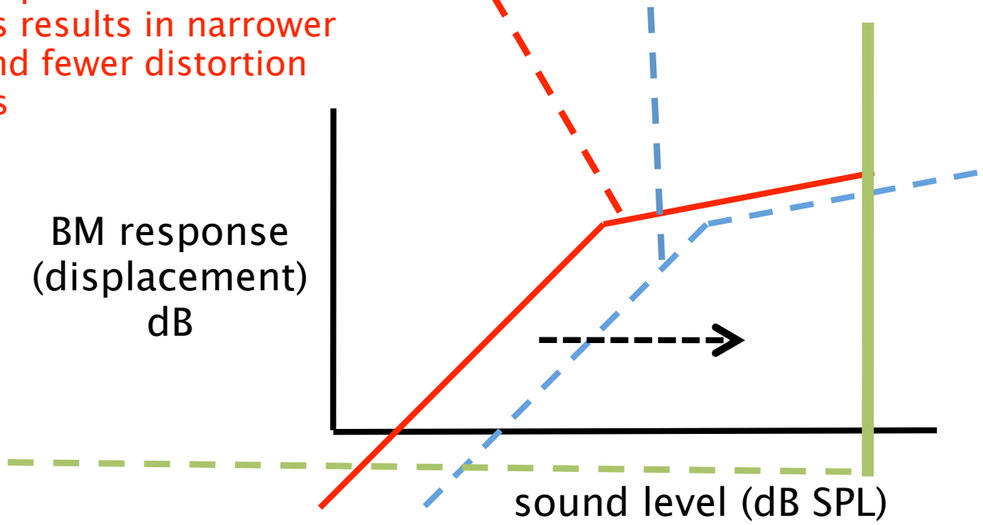


MOC (AGC) regulation

- Sustained background noise will reduce sensitivity
- responds on within-channel basis
- slow

Instantaneous compression

- default compression coeff. = 0.2 (10dB IN means 2 dB OUT)
- within-channel filtering limits spread of distortion
- adjustment of number of channels possible: increase in channels results in narrower filters and fewer distortion products



Acoustic reflex limiting action

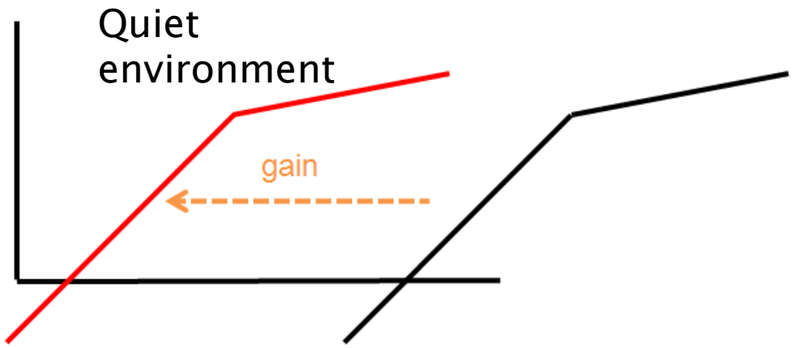
- driven (more effectively) by broadband signals
- responds on across-channel stimulus
- fast

notes

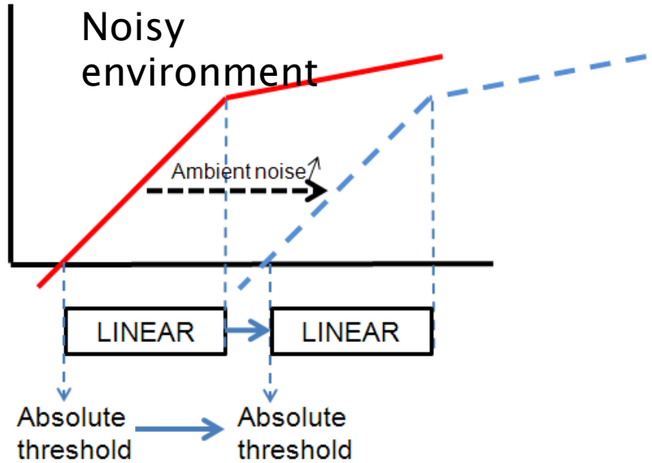
The hearing aid design in this slide tries to build the 3 level-regulating functions into the hearing aid. The most important component is the bandpass/compression/bandpass unit in each vertical pathway. These compress the signal in a biologically plausible way (instantaneous compression). The process is also moderated by the MOC suppression formed by a negative feedback loop. This loop has the virtuous property of filtering out many of the distortion products generated by the compression resulting in a smooth clear sound.
The acoustic reflex is incorporated into the aid by regulating the output of the aid to prevent high levels of sound.
A gain-component is added at the end of each channel.

So what does it do?

- Quiet sounds are made louder
  - ✓ by applying gain
    - -> decrease in Speech Reception Threshold in quiet (SRTq) and Absolute Thresholds



- Loud sounds are made quieter
  - ✓A closed fit/earplug attenuates the direct path of the sound
  - ✓The combination of instantaneous compression, MOC regulation and acoustic reflex keeps the level of the processed sound within set limits.
    - -> increase in Discomfort Thresholds
  - ✓Dynamic range changes: MOC moves the linear window as the ambient noise increases, the absolute threshold moves along with ambient noise



Benefits of the hearing aid:

- increase in sensitivity + increase of tolerance to loud sounds = increased dynamic range
- Protection from sudden loud sounds
- Increased willingness to engage in noisy situations (restaurants, parties, music events)
- Better speech in noise performance?

notes

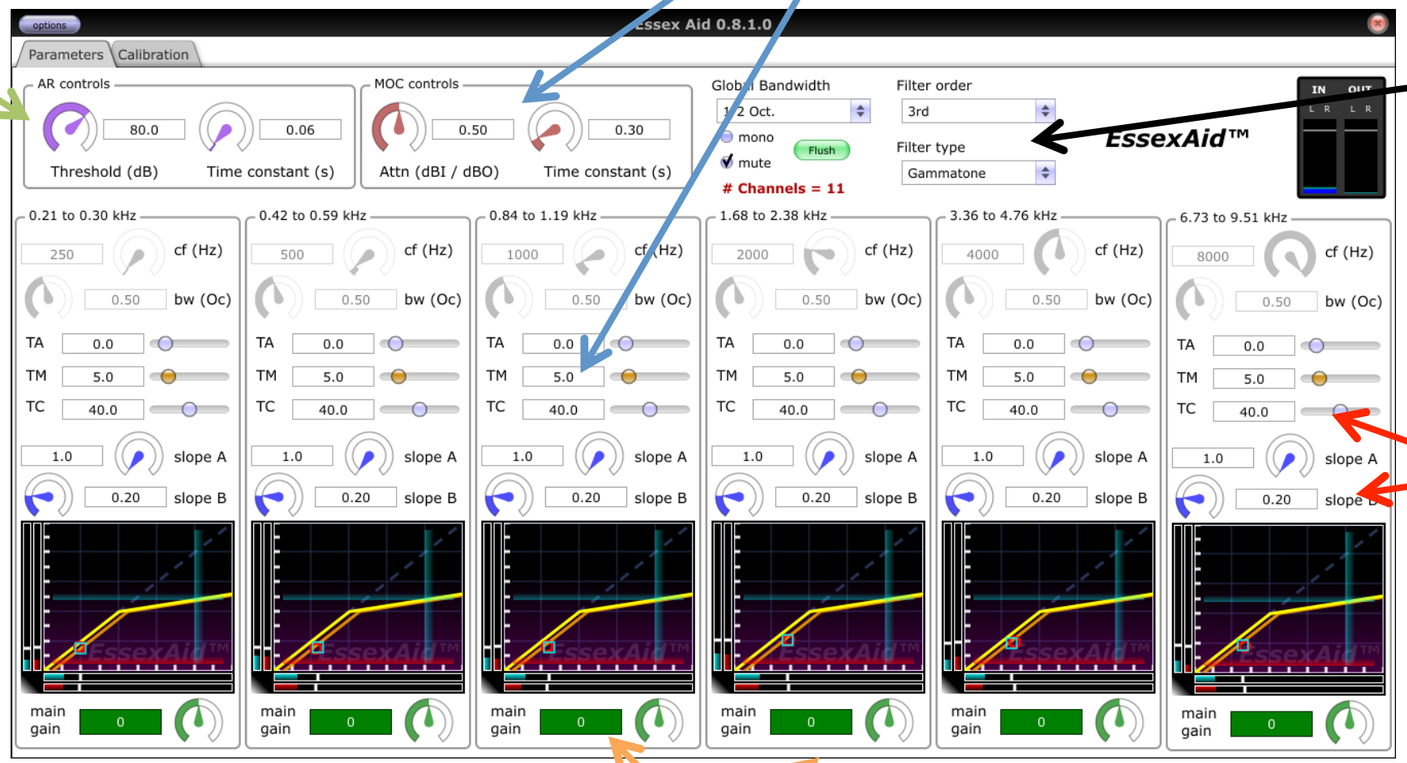
The first aim of the hearing aid is to make quiet sounds louder, in order to overcome the loss of sensitivity at specific frequencies. However, since many hearing aid users complain about loud environments being too loud, the Essexaid also aims to make loud sounds quieter (by using biologically-known level-regulating systems).

Fitting GUI

Fitting interface allows for real time adjustment of the hearing aid.

MOC response:
- MOC threshold (TM)
- MOC factor
- MOC time constant

Acoustic reflex
- AR threshold
- AR time constant



Filter type, bandwidth (number of filters)

Instantaneous compression:
- compression threshold
- compression coefficient

Gain adjustments

notes

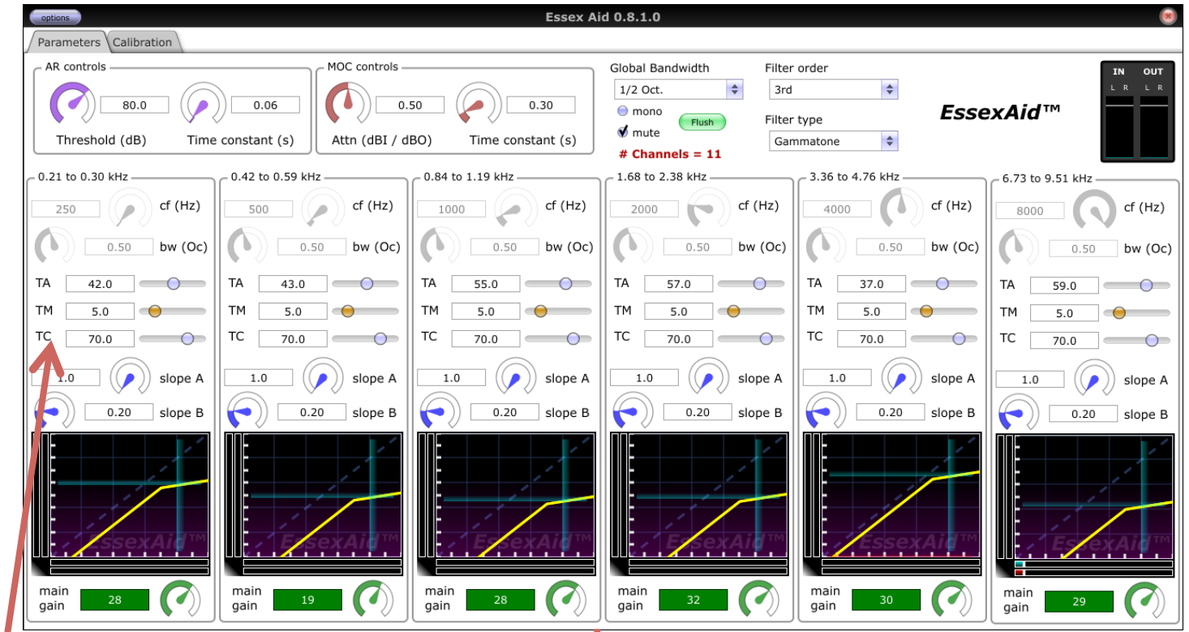
The setting of the aid parameters can be adjusted in real time by remote control while the aid is in place in order to find the best settings.

Fitting the EssexAid: preliminary data 1

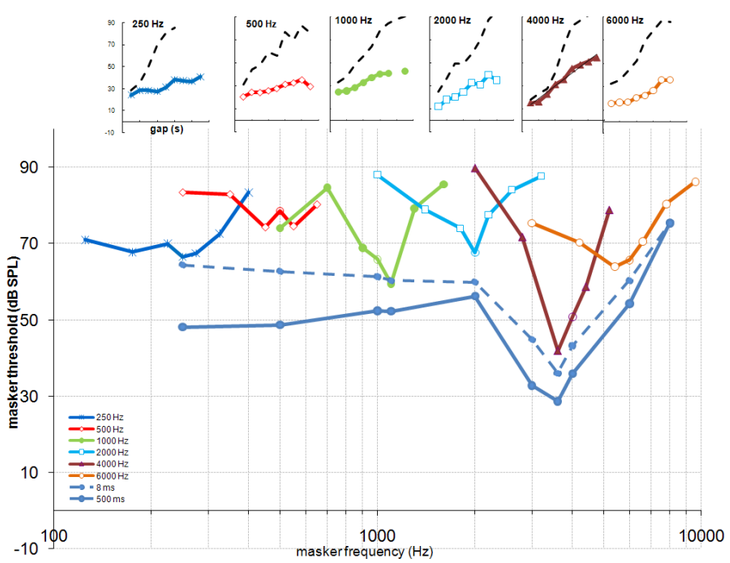
Testing protocol

Behavioural measures:
- Speech in quiet (SRTq): measures Speech Reception Thresholds for digit triplets .
- Speech in noise (SNR): measures Signal to Noise ratio for digit triplets in a fixed level babble.
- Discomfort: measures Discomfort Thresholds for real-life, impact stimuli (babble, shattering bottles, jackhammer).

Conditions: EssexAid and own aid (using general setting, program 1)



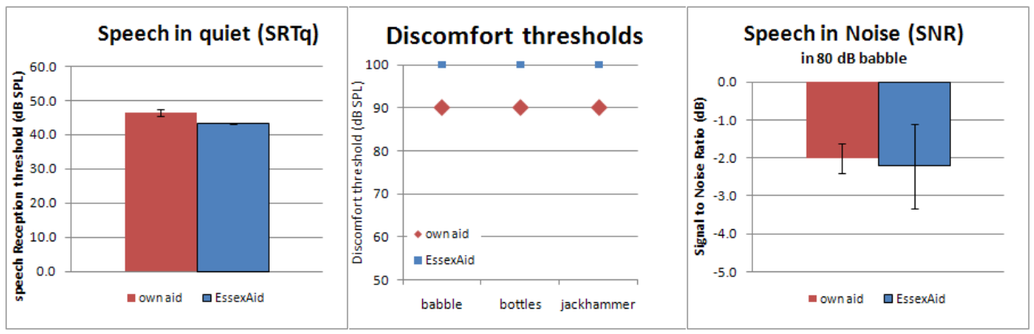
Example 1: IH14, F, 56 y.



Hearing profile:
- Raised thresholds
- Residual tuning
- Residual compression

EssexAid:
- need for gain
- no (or limited) need for instantaneous compression (TC = 70 dB input level, large linear section)

Results



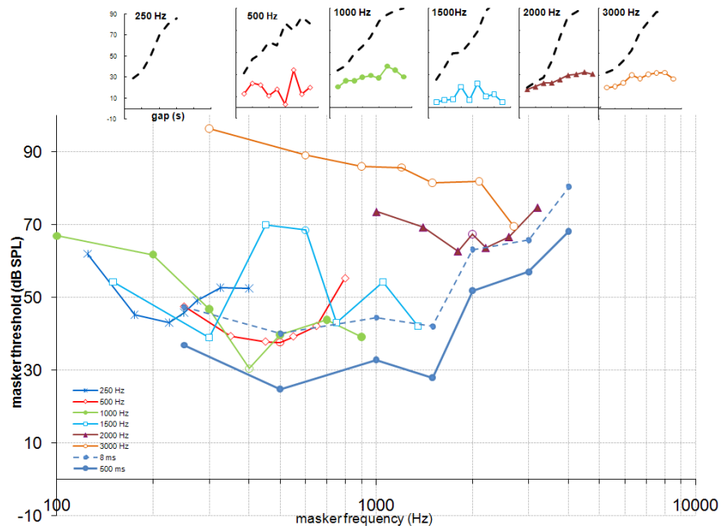
- Better sensitivity
- Higher discomfort thresholds (higher tolerance to impact sounds)
- Similar Speech in noise performance
- Listener very satisfied with EssexAid fitting.

notes

We are currently testing the aid using speech reception thresholds in quiet and in noise as well as discomfort thresholds. In this initial stage comparisons are made the listeners' regular hearing aid.
The fitting of the EssexAid is based on the listener's individual hearing profile which contains information on his/her sensitivity, frequency selectivity and cochlear compression.
Gain is applied in accordance with the absolute thresholds and information on the listener's compression is used when deciding how to adjust the instantaneous compression.
Example 1 shows a listener with raised thresholds and some residual compression. The EssexAid is fitted giving appropriate gain and only a small amount of instantaneous compression. The acoustic reflex is set at a generic value of 80 dB SPL. The results were very encouraging when compared with the listener's own hearing aid.

Fitting the EssexAid: preliminary data 2

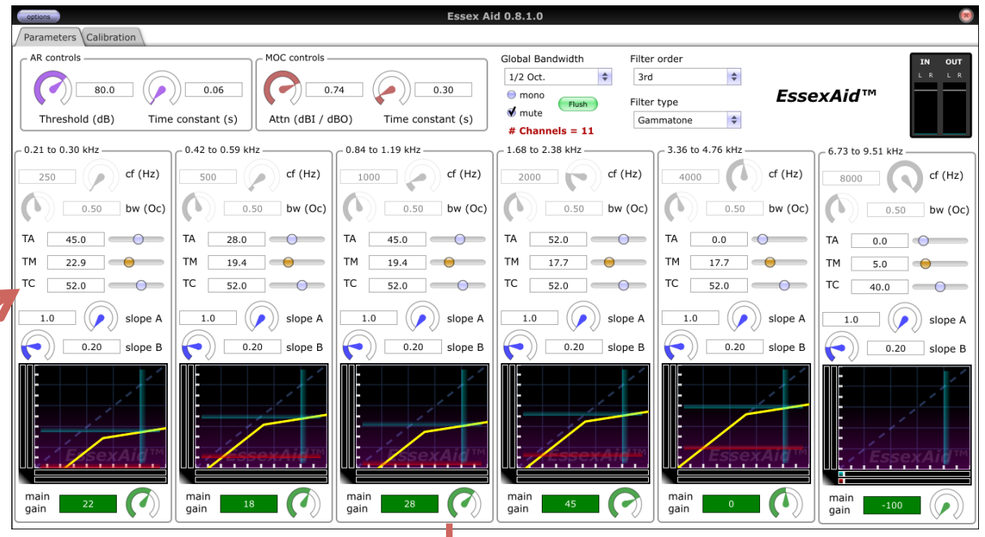
Example 2: IH08, M, 64 y.



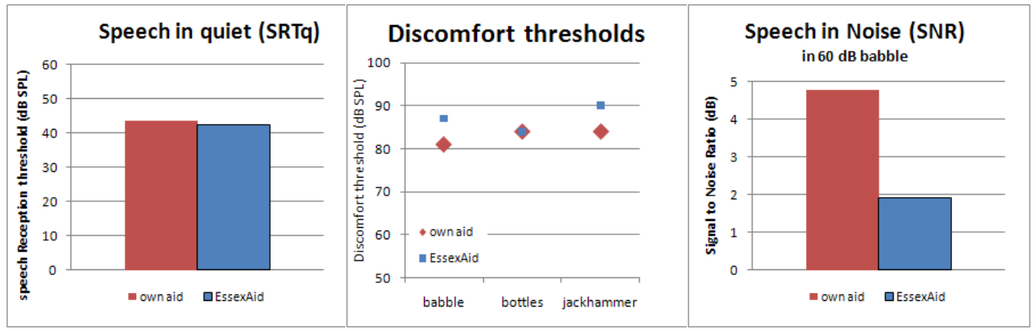
Hearing profile:
- Raised thresholds
- Poor tuning
- no compression

EssexAid:
- need for gain
- need for instantaneous compression

(TC = 52 dB input level)



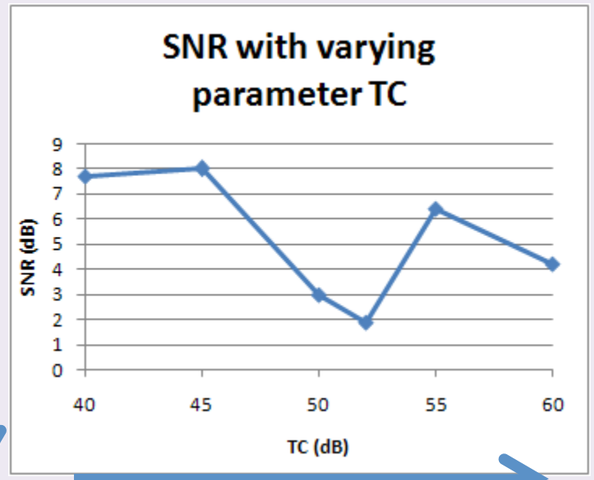
Results



- similar sensitivity than own aid.
- Higher discomfort thresholds (higher tolerance to impact sounds)
- Better Speech in noise performance
- Listener satisfied with the Essexaid fitting.

Where is the best point to put the compression threshold (TC)?

Better speech in noise performance



- Low TC= smaller linear section, substantial amount of instantaneous compression.
- High TC = large linear section, little instantaneous compression

In this case, only a small set of TC values generates the best performance.

Increase TC = increase in linear region

notes

Example 2 shows the hearing profile of a listeners with raised thresholds, poor frequency selectivity and very limited compression. The EssexAid is fitted as to give appropriate gain and considerable compression. The acoustic reflex and MOC are set at their generic values. The graph in the purple box shows an exploration of the ideal compression parameter (TC) using a speech in noise measure.
Again the results were encouraging showing a performance similar or better than the own hearing aid of the listener.

Rigorous testing is now required to establish a practical fitting procedure and to evaluate the benefits of the EssexAid.