

# Lecture 2

## Properties of Waves

- ▶ Frequency and period are distinctly different, yet related, quantities.
- ▶ Frequency refers to how often something happens.
- ▶ Period refers to the time it takes something to happen.
- ▶ Frequency is a rate quantity.
- ▶ Period is a time quantity.
- ▶ Frequency is the cycles/second.
- ▶ Period is the seconds/cycle.

## Example

- ▶ As an example consider a woodpecker that drums upon a tree at a periodic rate.
- ▶ If the woodpecker drums upon a tree 2 times in one second, then the frequency is 2 Hz.
- ▶ Each drum must endure for one-half a second, so the period is 0.5 s.

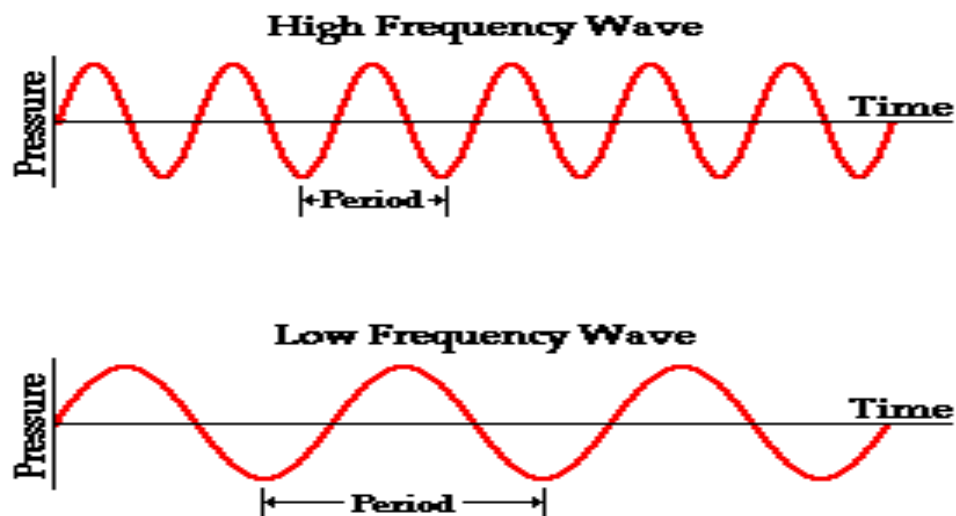
## Example

- ▶ If the woodpecker drums upon a tree 4 times in one second, then the frequency is 4 Hz; each drum must endure for one-fourth a second, so the period is 0.25 s.

- ▶ If the woodpecker drums upon a tree 5 times in one second, then the frequency is 5 Hz; each drum must endure for one-fifth a second, so the period is 0.2 s.

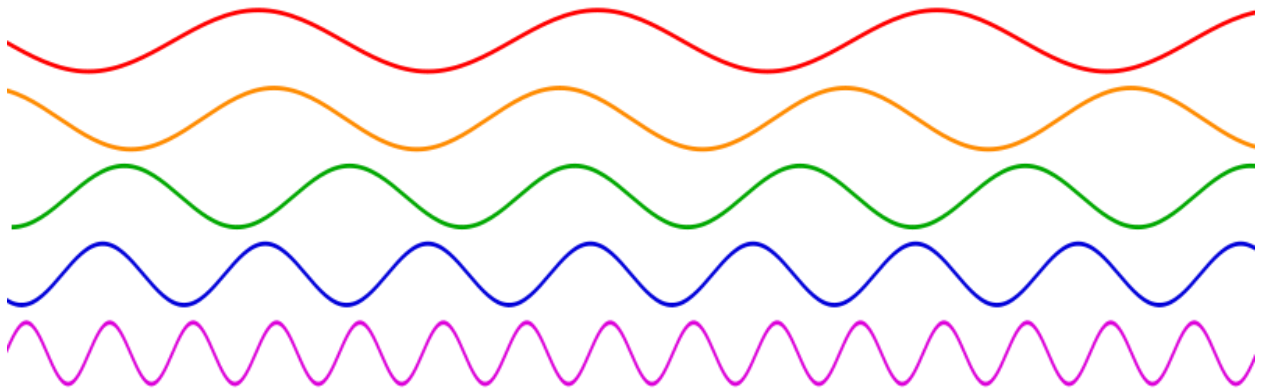
### Properties of Waves

- ▶ The frequency is simply the reciprocal of the period.
- ▶ For this reason, a sound wave with a high frequency would correspond to a pressure time plot with a small period.
- ▶ That is, a plot corresponding to a small amount of time between successive high pressure points.
- ▶ Conversely, a sound wave with a low frequency would correspond to a pressure time plot with a large period.
- ▶ That is, a plot corresponding to a large amount of time between successive high pressure points.
- ▶ The diagram below shows two pressure-time plots, one corresponding to a high frequency and the other to a low frequency.

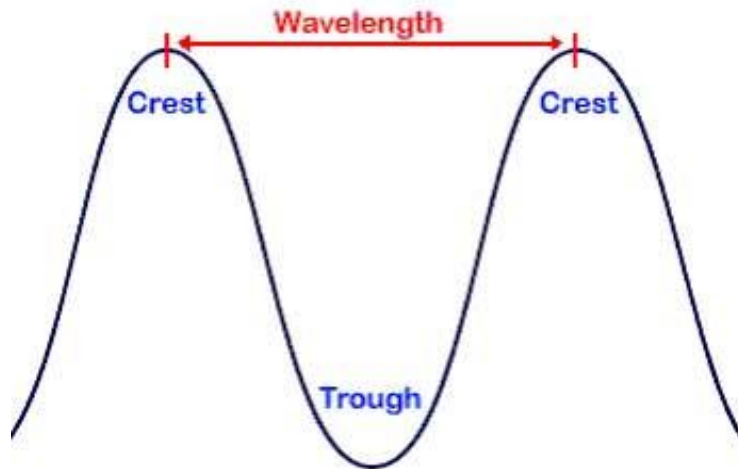


- ▶ Mathematically, the period is the reciprocal of the frequency and vice versa. In equation form, this is expressed as follows.

$$\text{period} = \frac{1}{\text{frequency}} \quad \text{frequency} = \frac{1}{\text{period}}$$



- ▶ The wavelength is another property of a wave. The **wavelength** of a wave is simply the length of one complete wave cycle.
- ▶ If you were to trace your finger across the wave in the diagram above, you would notice that your finger repeats its path. A wave is a repeating pattern.
- ▶ It repeats itself in a periodic and regular fashion over both time and space. And the length of one such spatial repetition (known as a *wave cycle*) is the wavelength.



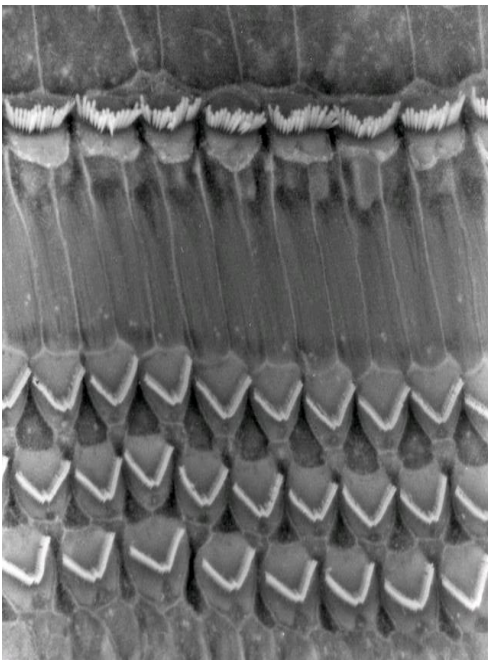
#### Acoustic Measurements:

1. Frequency- describes how many times per second a sound wave alternates from positive pressure to negative pressure and back to the starting value. Frequency is measured in hertz Hz.
2. Period- is the time taken for sound wave to complete one cycle. Period is measured in seconds or milliseconds and is equal to one divided by the frequency.
3. Wavelength- describes the distance a sound wave travels during one period of the wave. It is measured in meters.

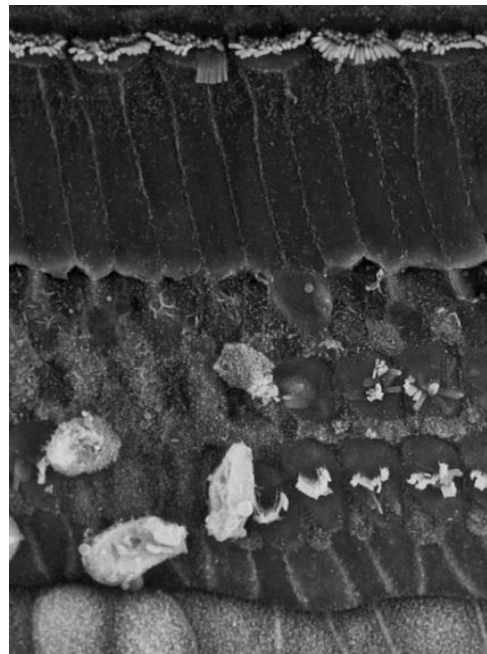
## Issues Faced by people with Sensorineural Hearing Loss:

1. Decreased Audibility
2. Decreased Dynamic Range
3. Decreased Frequency Resolution
4. Decreased Temporal resolution

**Normal hearing**



**Severe hearing loss**

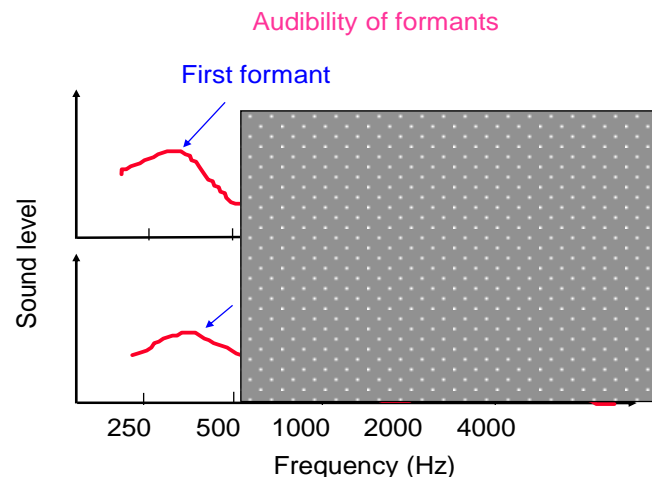


## 1. Decreased Audibility-

Hearing impaired people do not hear some sounds at all. People with severe or profound hearing loss may not hear any speech sounds, unless they are shouted at close range.

Hearing impaired people also have trouble understanding speech because essential parts of some phonemes are not audible. Sounds are recognized by noting which frequencies contain the most energy. The vowel *oo* for example, is differentiated from the vowel *ee* by the location of the second intense region or formant.

If for example, a hearing loss caused all frequencies above 700 Hz to be inaudible, as indicated by the shaded region. Although both sounds could be detected, the similarity of their first formants would make them sound almost identical.



**Figure 1.1** Similarity of the two vowels *oo* and *ee* when the second formant is inaudible because of hearing loss (grey area).

Source: Dillon (2001): *Hearing Aids*

The high frequency components of speech are weaker than the low frequency components. Furthermore, for approximately 90% of hearing impaired people, the degree of impairment worsens from 500 Hz to 4000 Hz.

To help overcome this difficulty, a hearing aid has to provide more amplification for frequencies where speech has the weakest components and where hearing loss is the greatest (usually high frequencies).

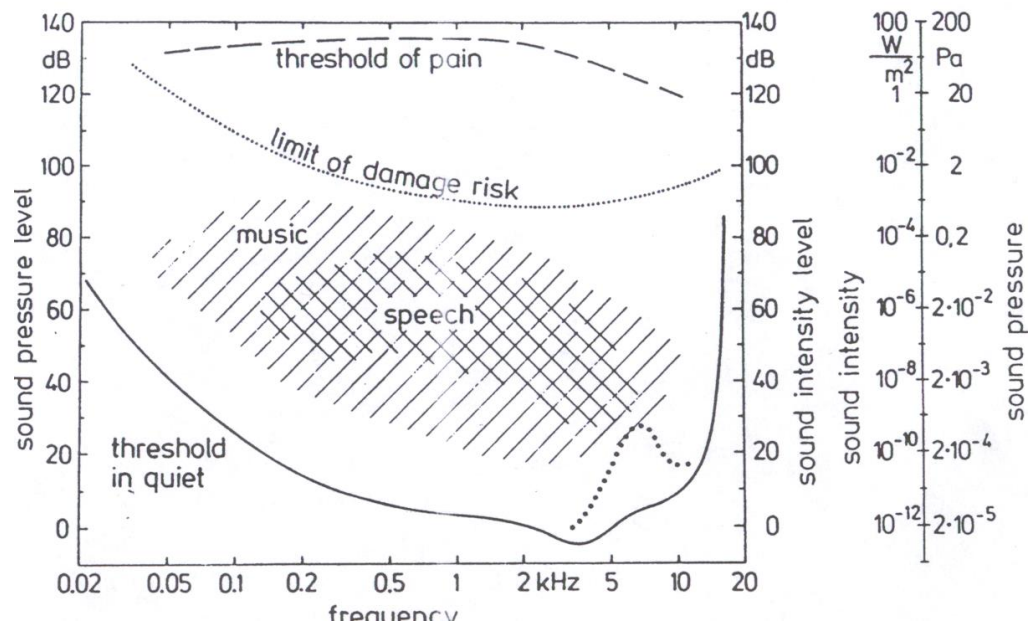
## 2. Decreased Dynamic Range-

A sensorineural hearing loss increases the threshold of hearing much more than it increases the threshold of loudness discomfort.

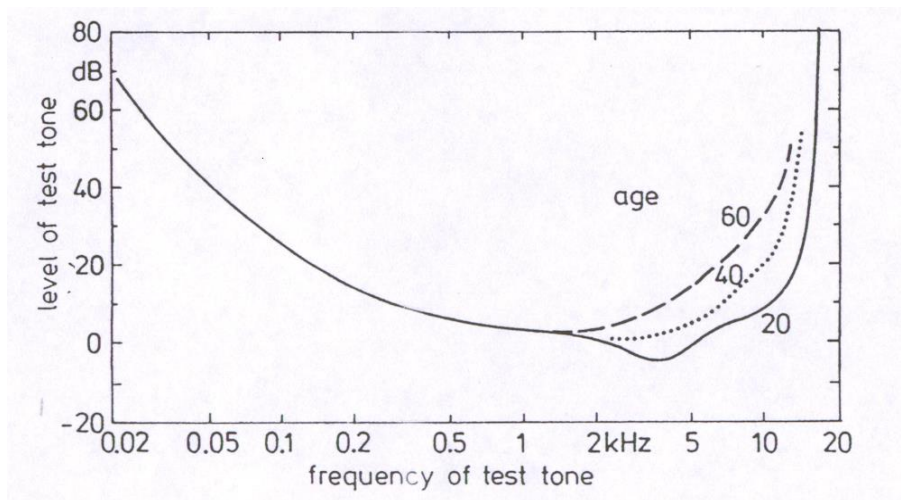
### **Dynamic Range of Hearing**

- ▶ The practical dynamic range could be said to be from the threshold of hearing to the threshold of pain
- ▶ Sound level measurements in decibels are generally referenced to a standard threshold of hearing at *1000 Hz* for the human ear which can be stated in terms of sound intensity: 0 to 130 dB

## Threshold of hearing

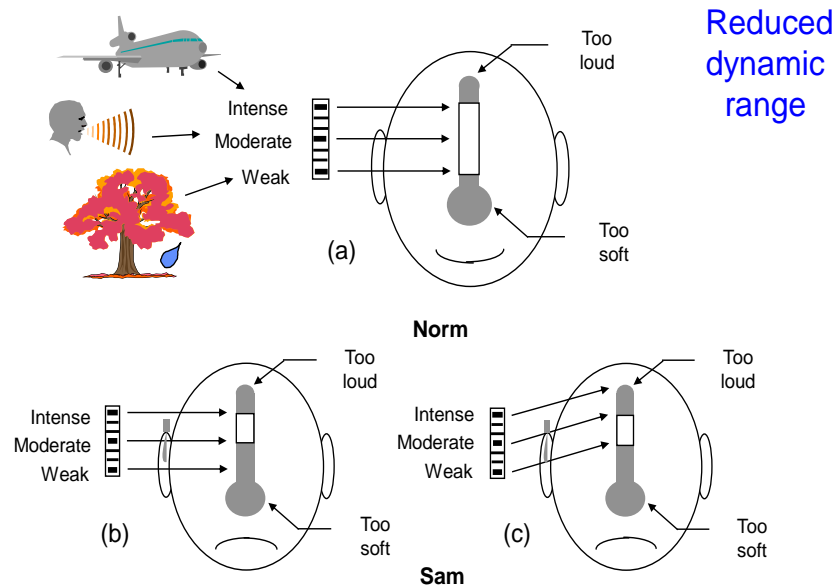


## Decreased Dynamic Range/Recruitment





Consequently, the dynamic range of an ear, the level difference between discomfort and the threshold of audibility, with a sensorineural impairment will be less than that of a normal hearing ear.



**Figure 1.2** The relationship between the dynamic range of sounds in the environment and the dynamic range of hearing for: (a) normal hearing, (b) sensorineural hearing loss without amplification, and (c) sensorineural hearing loss with a constant amount of amplification for all input levels.

Source: Dillon (2001): *Hearing Aids*

## Decreased Dynamic Range/Recruitment

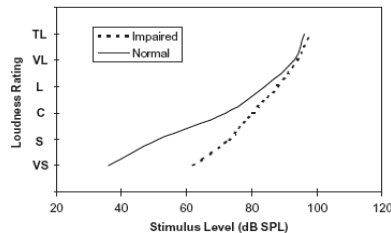


Figure 7.1. Typical loudness growth functions for a normal-hearing person (solid line) and a hearing-impaired person (dashed line). The abscissa is the sound pressure level of a narrowband sound and the ordinate is the loudness category applied to the signal. VS, very soft; S, soft; C, comfortable; L, loud; VL, very loud; TL, too loud.

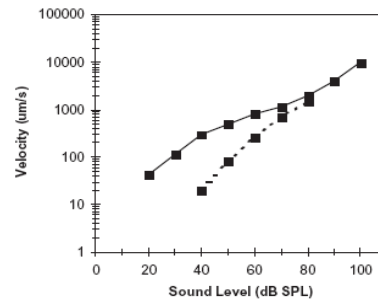


Figure 7.2. The response of a healthy basilar membrane (solid line) and one with deadened outer hair cells (dashed line) to best-frequency tone at different sound pressure levels (replotted from Ruggero and Rich 1991). The slope reduction in the mid-level region of the solid line indicates compression; this compression is lost in the response of the damaged cochlea.

### 3. Decreased Frequency Resolution-

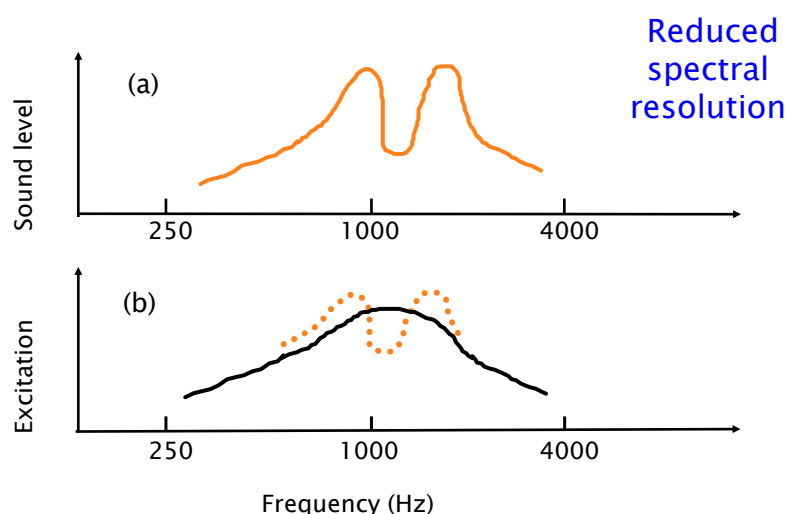
Another difficulty faced by people with sensorineural hearing loss is separating sounds of different frequencies. Different frequencies are represented most strongly at different places within the cochlea.

In an unimpaired cochlea, a narrow band sound produces a clearly defined region of relatively strong vibration at one position on the basilar membrane.

If a background noise contains some energy at a nearby frequency, the normal hearing ear can do a good job of sending separate signals to the brain, one signal for each region of intense activity in the cochlea. The ear has frequency selectivity or frequency resolution, which enables the brain to separate speech from noise.

A person with sensorineural hearing loss has decreased frequency resolution. This occurs because the outer hair cells lose their ability to increase the sensitivity of the cochlea.

Psychoacoustically, this shows up as flatter masking curves and tuning curves. The significance of this is that even when a speech component and a noise component have different frequencies, if these frequencies are close enough, the cochlea will have a single broad region of activity rather than two finely tuned separate regions. Consequently, the brain is unable to untangle the signal from the noise.



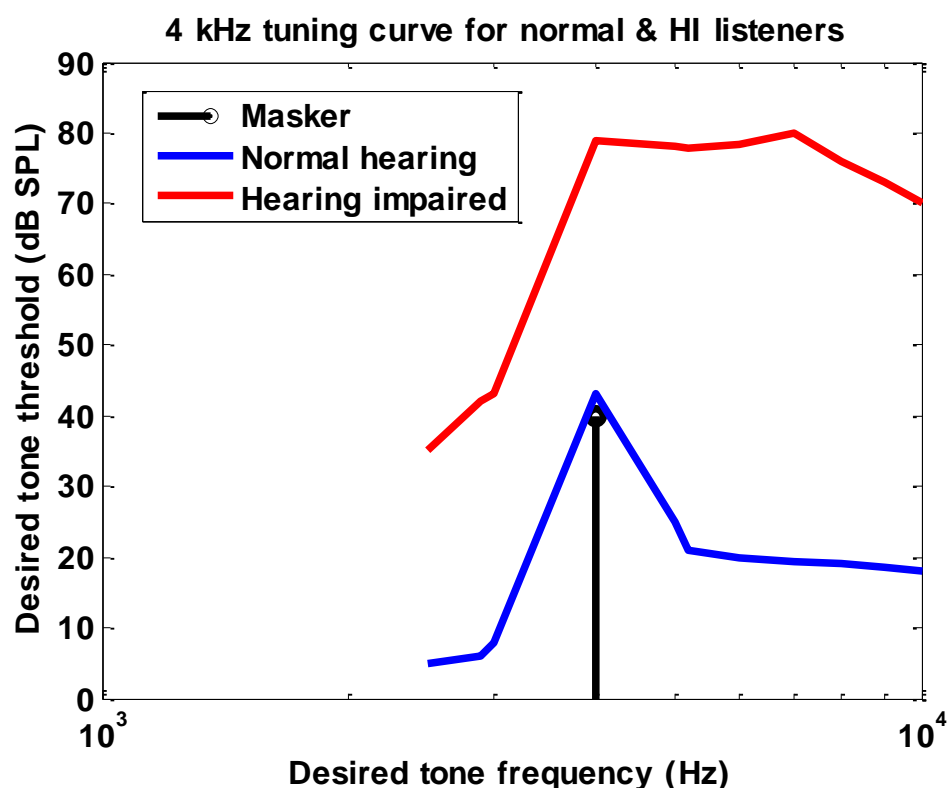
**Figure 1.3** (a) Sound spectrum, and (b) representation in the auditory system for normal hearing (dotted line) and sensorineural hearing impairment (solid line).

Source: Dillon (2001): *Hearing Aids*

There does not even need to be any noise for decreased frequency resolution to adversely affect speech understanding. If frequency resolution is sufficiently decreased, relatively intense low frequency parts of speech may mask the weaker higher frequency components. This is referred to as upward spread of masking.

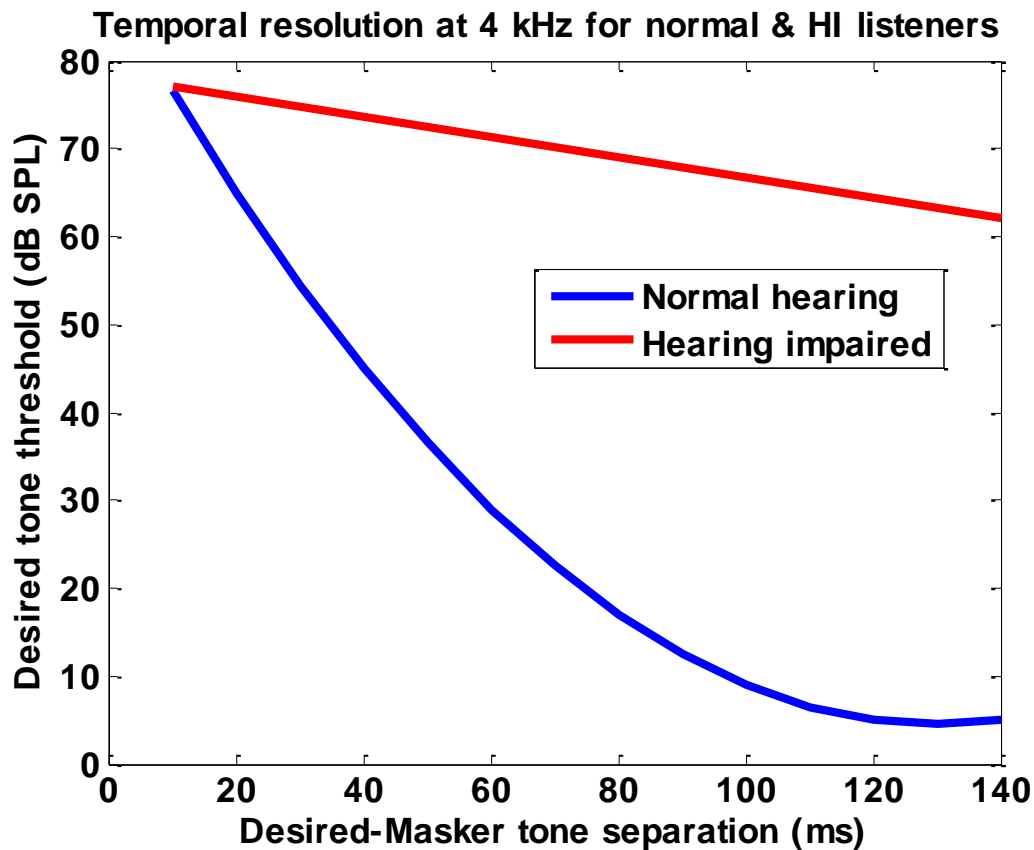
There is a second reason why decreased frequency resolution is a problem. Even normal hearing people have poorer resolution at high intensity levels than at lower levels. Hearing impaired people, especially those with severe and profound hearing loss, have to listen at high levels if they are to achieve sufficient audibility.

Consequently, hearing impaired people have difficulty in separating sounds is partly caused by their damaged cochlea and partly due to their need to listen at elevated levels.



#### 4. Decreased Temporal Resolution-

Intense sounds can mask weaker sounds that immediately precede them or immediately follow them. This adversely affects speech intelligibility. Many real life background noises fluctuate rapidly, and normal hearing people extract useful pieces of information during the weaker moments of the background noise. Hearing-impaired people partially lose this ability to hear during the gaps in a masking noise, particularly if they are elderly.



## Deficits in combination:

Each of the above aspects of a hearing loss (decreased audibility, dynamic range, frequency resolution and temporal resolution) can cause a reduction in intelligibility. In combination, they can cause a hearing-impaired person to understand much less than a normal hearing person in the same situation, even when the hearing impaired person is wearing a hearing aid.

Looked at another way, the hearing-impaired person needs a better signal-to-noise ratio (SNR) than does a normal-hearing person, if both people are to understand the same amount of speech. On average, the SNR required for a given level of speech intelligibility increases as the amount of sensorineural hearing loss increases. The average SNR deficit associated with a mild hearing loss is estimated to be about 4 dB, and the average deficit associated with a severe hearing loss is estimated to be about 10 dB. Despite these average trends, some individuals require a far higher or lower SNR than others with the same puretone hearing loss.

The situation is far simpler with conductive losses. These appear to cause a simple attenuation of sound, so that provided the hearing aid can adequately amplify sound, the normal cochlea can resolve sounds entering it just as well as the cochlea of someone with normal hearing.