Auditory Perception: Hearing Noise & Sound

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http://www.pc.rhul.ac.uk/staff/J.Zanker/PS1061/L5/PS1061_5.htm

coursework

- categories of visual illusions – collect, contrast, and compare
- systematic analysis to understand relationships, mechanisms, functions

DEADLINE: Monday 10 a.m. 9th March 2015

http://www.pc.rhul.ac.uk/staff/J.Zanker/PS1061/PS1061_essay_illusions.htm

NOTE: this coursework will be a test run for a new, improved submission system through MOODLE

http://www.pc.rhul.ac.uk/staff/J.Zanker/PS1061/PS1061_essay_illusions.htm

a possible way of categorisation?

Ursus Wehrli
THE ART OF TIDYING UP
ISBN: 978-3-0369-5297-0

http://www.pc.rhul.ac.uk/staff/J.Zanker/PS1061/PS1061_essay_illusions.htm
... and one more advert …

Inaugural Lecture
Prof. Patrick Leman

TONIGHT (here)

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Learning Outcomes

at the end of this lecture, you should be able to understand

• how auditory perception opens another window to the world
• the nature of sound: tones, mixtures, noise, complex patterns
• some more basics of sensory system: filters, tonotopic coding
• mechanisms of detecting & discrimination of pure tones
• the complexity of spoken language, the effects of hearing loss
• the nature of auditory scenes: localisation and segmentation
• how we can we generate auditory illusions ???

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questions about hearing

what is the significance of auditory perception in real life?

sounds signal events > alarm system
emotional balance: listening to music, screeching
communication

what are the most interesting problems in auditory perception ?

perceptual basis of harmony
recognition of voices
separating signal sources
influence of experience and knowledge
the nature of sound

A sound source is emitting (repeated) circular pressure waves (shells of air compression)

Similar to dropping a pebble into a still pond

properties of sound waves

A pure tone is represented by a sinewave (air pressure as function of space/time)

Amplitude and frequency (1/period, measured in Hz = cycles per second)

Corresponding to perceived loudness and pitch

making music: the scale

Notes of a musical score refer to the frequency generated - the pitch of a musical tone

Keys are arranged on the keyboard in the order of rising frequency of the musical tone generated (e.g., C-major diatonic scale)

Harmonic intervals are determined by characteristic frequency ratios

5/4 (major third)
4/3 (fourth)
3/2 (fifth)
2/1 (octave)
what happens to the waveform when you superimpose pure tones?

more complex sounds: chords, consonance, dissonance, vowels

white noise is the superposition of many tones with random amplitude and frequency (interfering ripples on the pond) (surface structure of the sea)

what happens when you randomly superimpose tones? (toss a handful of pebbles into the pond)

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combining frequencies: pitch

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frequency & amplitude of pure tones > perceived pitch and loudness

musical tones are combinations of pure tones: fundamental (determines pitch) + harmonic frequencies (determine timbre)

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mechanics of transformation

http://www.hhmi.org/biointeractive/neuroscience/cochlea.html

mechanical stimulation >> pressure waves in cochlea >> basilar membrane "resonates"

unrolled cochlea

>> stretched basilar membrane

cochlear tip

peak of travelling wave on basilar membrane depends on frequency of stimulus: pitch of tone

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filtering > tonotopic maps

tone frequency is converted to location !! (mapping...)

filter tuning: preferential response of a sensor to a dedicated stimulus range (here: frequency)

mechanical activation

lateral inhibition in the auditory pathway

g. v. bekésy, 1967

electrical activity

distance from oval window [mm]

additional frequency tuning is achieved !! (~ receptive fields)

 auditory filter: tuning to frequency (pitch) in the peripheral auditory system

sensory map: cortical representation of pitch as function of location (tonotopy)

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frequency tuning > perceived pitch

electrophysiological measurements in auditory pathway

> frequency tuning of individual neurones: "preferred" tones

frequency tuning measured in perception by masking

filter sets cover full range of frequencies like digital audio systems!

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psychophysical masking experiment:
• detect a (target) tone in presence of another (masking) tone
• vary intensity of masking tone until target disappears/reappears: threshold

you only can hear the piccolo if the bassoon is played very softly: masking !!!

distance masking

masking > frequency channels

• determine tuning curve by systematic variation of masking frequency;
  >> bandwidth of the frequency filter detecting the target

this filter tuning is the basis for the perception of pitch!

psychophysical masking experiment cont.:
• vary frequency of masking tone to determine threshold for different frequencies

threshold amplitude

questions?
the ecology of sound intensity

<table>
<thead>
<tr>
<th>Intensity (dB)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Threshold of hearing</td>
</tr>
<tr>
<td>10</td>
<td>Normal breathing</td>
</tr>
<tr>
<td>20</td>
<td>Leaves rustling in a breeze</td>
</tr>
<tr>
<td>30</td>
<td>Empty movie theatre</td>
</tr>
<tr>
<td>40</td>
<td>Holloway campus at night</td>
</tr>
<tr>
<td>50</td>
<td>Quiet restaurant</td>
</tr>
<tr>
<td>60</td>
<td>Two-person conversation</td>
</tr>
<tr>
<td>70</td>
<td>Trafalgar Square</td>
</tr>
<tr>
<td>80</td>
<td>Vacuum cleaner</td>
</tr>
<tr>
<td>90</td>
<td>Huge waterfall (Niagara)</td>
</tr>
<tr>
<td>100</td>
<td>Underground train</td>
</tr>
<tr>
<td>120</td>
<td>Propeller plane at takeoff</td>
</tr>
<tr>
<td>140</td>
<td>Jet at takeoff (Heathrow)</td>
</tr>
</tbody>
</table>

danger level

- Hearing loss from prolonged exposure

pain level

- Physical intensity (SPL = sound pressure level) is recorded as 'perceived loudness'

measuring perceived loudness...

perceived loudness can be measured by comparing successively presented tones (different frequency) > decide which one sounds louder (two interval forced choice : 2IFC)

comparing many frequencies >> curves of equal loudness

... what can you hear ???

combine loudness and frequency detection in Audiogram (audibility function, AF) : detection threshold as function of frequency (20Hz – 20 KHz)

equal loudness contours are determined by matching the perceived intensity of tone pairs at various base intensities

(1000 Hz reference: close to 0 dB SPL at threshold)

speech
Auditory events can be complicated patterns of frequency and intensity (the ‘spectrum’) which is modulated as function of time.

Scientists use ‘spectrograms’, or ‘sonograms’: frequency composition as function of time to display and analyse real sounds. The three musical tones can be seen in the schematic spectrogram as succession of different fundamental 
& harmonic frequency clusters.

The complexity of a spoken word:

Each spoken word generates a complex pattern of frequency and intensity (spectrum), which is modulated as function of time recorded as:
- spectrogram (time, freq., intensity)
- waveform envelope (microphone)

Imagine how difficult it is to recognize the same word form different speakers, or the voice of a particular speaker...

The spectrum of human speech:

Speech sounds cover a wide range of the audible spectrum. Vowel sounds are mainly in the lower frequency region. Consonants cover almost the entire range. Telephone systems cut off the upper part of the spectrum with minimal effects on speech recognition!!!
There are many different kinds of auditory impairments, apart from complete deafness:
- Presbycusis: selective high-frequency hearing loss with age (ongoing)
- Noise exposure can lead to temporary threshold shifts (auditory fatigue) and permanent (partial) deafness
- Tinnitus: continuous humming or ringing
  >> leads to suppression

**Hearing Loss**

**Auditory Space**

How does auditory space represent events in a four-dimensional world (3D + time)?

In vision, we have 2D-images, can easily localise objects in the visual field and see several objects at the same time.

The ear is a 1D sensor (a microphone samples one point in space):
- How can we hear in two, or three dimensions?
- How can the auditory system localise objects?
- How can we hear several objects at the same time?

**Sound Localisation**

There is no direct representation of auditory space:

- Pinnae: crucial for sensation of space (earphones); locate elevation (up-down)
- Inter-aural processing to find azimuth (left-right) of sound source:
  - Intensity differences (I I D): acoustic "shadow" of the head
  - Temporal or phase differences (I T D): inter-aural delays of 10 - 650 μsec

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<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Normal AF</th>
<th>Impaired AF</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1000</td>
<td>1000</td>
<td>1000</td>
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</tbody>
</table>

**Sound Pressure Level (dB)**

- 0 dB (frequency dependent)
- 10 μsec <= 3 mm

**Auditory Stereo ~ Stereovision**
the cocktail party effect

it is easy (for young folk) to single out one particular voice from
the background of a noisy pub, or to pick up the tune of a single
instrument from a large orchestra

how can this be achieved? the mixture of wavefronts
hitting the ear has an overwhelming complexity!
(more like the 'rippled' surface of a pond in a storm)
masking: the detection of a tone is impaired if
another tone or noise is presented at the same time
masking depends on proximity in space and
similarity in frequency composition

• binaural unmasking: if spatial distance or difference in frequency increases,
  separation is easier - binaural information (subtract signals from the ears)
• high-level effects (attention, familiarity of voice, language) & sensory fusion

auditory illusions

we can create illusions in the auditory
system like in the visual system
Shepard's eternally rising tone: an
impossible acoustic object?

... questions

???
summary: auditory perception

- the auditory ‘channel’ is an important source of sensory information
- the ear is a highly sensitive & intelligent device to pick up & convert waves
- frequency filtering is the basis of perceiving pitch
- sound intensity is the second stimulus variable (ecological significance!)
- spoken words: complex patterns of frequency & intensity (spectrogram)
- speech covers a wide range of audible spectrum, affected by hearing loss
- sound can be localised by calculating intensity and phase differences
- auditory localisation can work in difficult environments (cocktail party)

http://www.pc.rhul.ac.uk/staff/J.Zanker/PS1061/LS/PS1061_5.htm
see also chapter 7 & 8 of Zanker, 2010
and chapter 15 in H.Barlow & J.Mollon, eds. The Senses, 1982

... have a productive reading weekend !!!