Neurobiology of Hearing

Acoustic-motor reflexes

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Trastornos Audio Motores
Audiomotor Diseases

Startle reflex
Audiogenic epilepsy

translational research
Clinic
Auditory reflexes: summary

• The involuntary movements triggered by auditory stimuli (audio-motor reflexes) are described.

• In this class, the importance of such reflexes for the organism is analyzed since they are responsible for protecting the auditory receptor (middle-ear reflexes); for locating the source of the sound (orientation reflex), and for protecting the individual (auditory startle reflex).

• The class also addresses the neuroanatomical substrate of these reflexes.
**Aims:**

1) To describe the different auditory reflexes
2) To determine their functions
3) To highlight the importance of auditory reflexes in Clinical Diagnosis and in Research
4) To determine the neuroanatomical substrate of the reflexes
Classification of movements

- Reflex responses
- Patterns of rhythmic movement
- Voluntary movements
What is a reflex?

Reflex responses are involuntary, rapid and stereotyped movements elicited by a stimulus.
Classification of reflexes

- Nature of the stimulus
- Localization of the reflex
- The role it plays
- Muscle groups involved
The nature of the stimulus is a sound

Acoustic motor reflexes: types

1- Middle-ear reflex
   *Function: To protect the cochlea*

2- Orientation reflex or Preyer reflex
   *Function: Location of the sound source*

3- Auditory startle reflex
   *Function: To protect the individual*
Structure of the middle ear

- **3 small bones** *Malleus, incus and stapes*

- **6 ligaments**
  - 3 for the malleus
  - 2 for the incus
  - 1 for the stapes

- **2 Muscles**
  - Tensor muscle of tympanic membrane
  - Stapedial muscle

- **A sound cavity**
Scheme of the propagation of sound through the middle ear
Why do we have three bones?

Because this is the lowest number permitting TWO articulations
Why do we have two articulations?

To individualize the effect of each of the muscles.
What is the middle-ear reflex?

- Involuntary bilateral contraction of the muscles of the middle ear:
  - stapedial muscle
  - tensor muscle of tympanic membrane

- Contraction of the muscles elicits an increase in the rigidity of the chain of bones

- They reduce the vibrations and the acoustic signal arriving at the middle ear.
  - They reduce gain
  » protecting hair cells
When do middle-ear reflexes occur?

1. Middle-ear reflexes are activated by sounds that are:
   - loud (> 80dB)
   - low-frequency (< 2kHz)
   - long-duration (>200ms)

   Middle-ear reflexes are not activated by sounds that are:
   - low-intensity (of any frequency)
   - high-frequency (of any intensity)
   - short sounds

Contraction as a function of intensity and frequency
Acoustic trauma or deafness due to noise

When someone is subjected to intense sounds at more than 90 decibels, a lesion of the hair cells of the organ of Corti may occur.

Damaged organ of Corti:
Absence of several outer and inner hair cells

Normal organ of Corti:
3 rows of outer hair cells and a row of inner hair cell
When do middle-ear reflexes occur?

2. The muscles contract when speaking, protecting from fatigue, interference or own sounds

* They contract before speaking

* This protects the hair cells of the organ of Corti

stapedius reflex reduces sound pressure levels reaching the inner ear hair cells by approximately 20 decibels
Other implications of the contraction of the muscles of the middle ear

* -It allows to listening, for the attenuation of the low frequency components
  -It allows differences in frequency to be discriminated
  -It allows to diminished 20dB in human

Sounds of low frequency mask high-frequency components of sounds
TESTS FOR PRE-NEURAL HEARING LOSS

Tests that are used to identify PRE-NEURAL lesions are: (1) otoacoustic emissions, (2) Electrocochleography (3) Impedance testing, and (4) diagnostic hearing evaluations. The most frequent cause of PRE-NEURAL hearing loss is noise exposure. Noise exposure can occur in the form of occupational (military, industrial) or recreational (hunting, loud music, motorcycles). A common cause of PRE-NEURAL hearing loss is genetic. We now have identified several hundred genes that result in acquired hearing loss. PRE-NEURAL hearing loss can also be associated with health conditions such as diabetes, autoimmune disease, frequent and chronic ear disease, and Meniere’s disease.

OTOACOUSTIC EMISSIONS

Otoacoustic emissions measure the cochlear microphonic, which is an electrical response produced by the outer hair cells of the cochlea. These outer hair cells are often referred to as the amplifier of the inner ear. The absence of otoacoustic emissions suggests outer hair cell damage, which is a PRE-NEURAL finding and represents 95% of all adult hearing loss.

ELECTROCOCHLEOGRAPHY

Electrocochleography (EcochG) is also a test that records the electrical activity of the cochlea. Abnormal electrical cochlear activity is characteristic of patients with Endolymphatic Hydrops/Meniere’s Disease and represents PRE-NEURAL damage. The presence of normal electrical activity within the cochlea followed by an absent neural response suggests a NEURAL LESION.

IMMITTANCE

Impedance testing is both sensitive and specific for abnormalities of the middle ear, which are considered PRE-NEURAL causes of hearing loss. Fluid or congestion behind the eardrum (Eustachian Tube Dysfunction) can be identified by impedance testing as well as the mobility of the middle ear bones. These conditions can be treated medically and/or surgically and require appropriate medical referral.

HEARING EVALUATIONS

Although hearing evaluations are routinely used in most diagnostic centers, routine hearing tests do not differentiate between PRE-NEURAL and NEURAL lesions without more comprehensive tests.

TESTS OF NEURAL HEARING FUNCTION

NEURAL hearing loss is associated with damage to the auditory nerve and/or its central pathways. Tests that are used to identify NEURAL hearing loss are Auditory Brainstem Response tests (ABR) and Acoustic Stapedial Reflexes (ASR). Causes of NEURAL hearing loss include: (1) space occupying lesions of the VIII hearing nerve, (2) demyelinating diseases such as Multiple Sclerosis, (3) inner hair cell loss, and (4) neuropathy of the hearing nerve. Patients with NEURAL hearing loss are not candidates for hearing aids and depending on the degree of hearing loss and etiology.

http://www.oconehearing.com/ClinicalServices.htm
Characteristics of the innervation of the muscles of the middle ear

- TWO independent nuclei next to genu of facial nerve.
- Fibers borne by the facial nerve.
- Connections with the olivo-cochlear system.

Stapedial muscle

- ONE/TWO nuclei next to the exit of the V pair.
- Fibers borne by the trigeminal nerve.
- Connections with the cochlear nuclei.

Tensor of tympanic membrane
Middle-ear muscles innervation

Motoneurons of the cat tensor muscle of tympanic membrane

Middle-ear muscles innervation

Thompson y cols., JCN 231:270-279 (1985)

Stapedial motoneurons in primates
Middle-ear muscles innervation

Modified from Rouiller, 1992
2- Preyer reflex

- Orientation of the ears towards the source of the sound when unexpected auditory stimuli occur

  - In species with immobile ears, orientation is performed by moving the head.

  - In species able to move their ears, orientation depends on coordinate movement of the head and ears.
Which motor centers are involved?

- The facial motor nucleus

In monkeys and cats, the motoneurons responsible for the ear’s movement are located in the medial subdivision of the facial motor nucleus.
Which motor centers are involved?

- The paralemniscal region

-The motoneurons responsible for moving the head are located in the region medial to the lateral lemniscus, the paralemniscal region, which is also involved in the movement of the ears in some animals (cat)
Which sound characteristics are related to information about the position of the source of the sound?

Sound carries three types of information:

**HRTF** = The head-related transfer function.

**ITD** = Interaural Time Difference

**IID** = Interaural Intensity Difference

The pinnae are of importance in sound localization since they reflect incoming sound in ways that depend on the angle of the source.
A. Pathway of the ITD

B. Pathway of the IID
Cochlear Root Neurons (CRNs)

In the rat, the CRNs innervate the facial (7n) motoneurons that move the pinna
How does the auditory information arrive at the motor centers involved in the Preyer reflex

Cochlea

paralemniscal region
3- Auditory Startle reflex

- Contraction (reflex) of a varying number of muscles when challenged by an intense, unexpected sound.
- This is accompanied by a response of the autonomic nervous system (characterized by an increase in blood pressure and heart rate.)
- Which prepares the organism for situation of alert and helps to preserve the individual's life.
What is the startle reflex?

In the rat, a general response of flexion is observed, with a hunching of the shoulders, dorsiflexion of the neck and a general shortening of body length. The sudden contraction leads the animal to jump, proportional to the intensity of the startle response.

In primates, the startle response occurs as a generalized contraction of the striate muscles of the skeleton, mainly on the face, neck, shoulders and top proximal parts of the arms.
Up to two months of life, when a baby is startled, its arms extend forwards with the palms upwards and the thumbs flexed. This reflex occurs when a baby is startled by an intense sound or it feels as though it were falling. It is specifically termed the moro reflex.

Sometimes babies are startled by their own crying, which elicits this reflex.

The absence of this reflex may indicate the presence of a lesion or disease.
Which stimuli trigger the auditory startle reflex?

In both humans and laboratory animals, the stimuli that most readily activate the ASR are high-intensity sounds, above 80 dB SPL.

White noise (sounds comprising a broad frequency range) is more effective than pure tones.

There is no fine spectral processing of auditory information. The stimulus being more effective as it activates more information channels.
What function does the ASR serve?

It activates a defensive stance against a possible aggression or alerts about unexpected events.

It prepares the individual for fight

Although surprising, it may elicit an intimidatory stance towards attack by a predator

The duration of the ASR is 200 ms, after which movements aimed at fight, escape or orientation begin
Many substances modify the ASR

Haloperidol, Pimozide (antagonist)

DOPAMINE (agonist)

Anxiolitics

Antipsychotics

Ethanol

Cocaine

Apomorphine

Amphetamine

Bin to receptors
Like any reflex, conditioned responses may be induced
This provides an important tool in clinical and basic research into the CNS.
Which parameters are used to characterize and evaluate the ASR?
How is the ASR assessed in clinical practice?

Using a normal (A) or specific (B) electromyograph, muscle contraction is measured after exposure to an intense sound.
How is the ASR assessed in clinical practice?

Electromyograms of the different muscles are obtained and the response parameters are assessed.
Electromiography - ASR

Registros de la actividad electromiográfica tras el primer estímulo auditivo
ASR differences between man and woman
Applications of the ASR

• **In clinical practice**:
  – *As a rapid, simple, cheap, innocuous and highly informative method.*
  – *To assess the state of the acoustic-reflex components of the auditory system*
  – *To evaluate the status of the auditory system*
  – *For the early detection and follow-up of neurological and psychiatric disturbances: Parkinson’s disease, reflex epilepsy due to surprise, hyperekplexia, substance abuse ...*
  – *For evaluating therapies*
Evaluation of startle reflex in experimental animals

http://www.usal.es/~incyl/Miembros/LopezGarciaD/Medicion%20RAS.mov
The auditory Startle reflex as a tool for

Pharmacological assays

Asses substance abuse

Assess Neurological Diseases

Assess Psychiatric Disorders

Assess Therapies employed
Which auditory nuclei are involved?

Cochlear Root Neurons

Pontine Reticular Neurons

Motoneurons

Muscles

Cochlear Root Neurons
Modifications of the ASR

- Habituation
- Previous stimuli
- Positive stimuli
- Drugs
- Sensitization
- Fear potentiation
- Anxiety
- Stress
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Prepulse Inhibition

Auditory, tactile or visual stimuli elicit this inhibition.

- PPI occurs in all mammals; it is not a conditioned phenomenon

- Neither habituation nor extinction occurs

- PPI measures how the CNS modulates motor responses to the stimulus triggering the startle so that it will not interfere with the processing of the preceding stimulus (sensory)
PPI: genre differences

Qazi Rahman, Behavioral Neuroscience 2003
• The inhibition is higher in males
- PPI is reduced in many mental disturbances:
  - Schizophrenia
  - Obsessive-compulsive disorders (OCD)
  - Epilepsy of the temporal lobe with psychosis
  - Post-traumatic stress disorders (ex-combatants, rape victims…)
  - Hyperactivity
  - Attention Deficit
Patients with schizophrenia or with "schizoid-like disorders" and rats treated with drugs exerting psychotic effects show a clear PPI deficit.

- Deficits in pre-pulse inhibition in adult patients can be reversed with antipsychotic medication.
PPI is a Diagnostic tool

- Helps to establish an early diagnosis
- It can provide an index of the severity of a pathology
- Serves to test the efficiency of treatment in an objective way
A possible pathway for the PPI
Degenerative diseases
Auditory reflexes - Summary

- Triggered by a sound

- Three: Middle-ear reflex, orientation reflex and auditory startle reflex

- Ethological value: for survival

- Important in clinical practice:
  - Its assessment allows the brainstem to be evaluated
  - It can be used as a diagnostic tool in perinatal medicine
  - It can be used as a diagnostic tool in neurology and psychiatry
  - It can be used as a diagnostic tool in otorhinolaryngology

- Important in Basic Research
Long-term functional recovery in the rat auditory system after unilateral auditory cortex ablation

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Abstract

Conclusions: unilateral auditory cortex ablation results in poor auditory recovery. After bilateral auditory cortex lesions, the auditory system is able to recover function in adult rats at 90 days after surgery. These lesions produce a robust deflection towards the injured auditory cortex, which is observed in the auditory brainstem response (ABR) and the auditory evoked potential (AEP). This suggests that the ABR and AEP are reliable markers for assessing auditory recovery after unilateral auditory cortex ablation.

Keywords: Auditory descending pathways, corticofugal projections, acoustic startle reflex, para-aural brainstem plasticity, poppy hallucination, auditory brainstem response.

Introduction

The auditory cortex (AC) is a region of the brain that is critical for the processing of auditory information. It receives input from the thalamic nuclei, which in turn receives input from the auditory thalamus. This projection is thought to be important for the processing of complex sounds and the integration of auditory information with other sensory modalities. Previous studies have shown that lesions of the auditory cortex (AC) can result in auditory deficits, including hearing loss and auditory hallucinations.

Materials and Methods

- Unilateral auditory cortex ablation was performed by injecting a solution of 3% formalin into the auditory cortex of adult rats. The lesions were made at the level of the auditory cortex, extending into the inferior colliculus. The lesions were then verified histologically.
- Behavioral testing was performed using a series of auditory and visual stimuli, including pure tones and sounds with varying frequencies.

Results

- The results showed that unilateral auditory cortex ablation resulted in a significant decrease in the ABR and AEP responses, indicating a loss of auditory function.
- However, the ABR and AEP responses recovered significantly over the course of 90 days, indicating a robust recovery of auditory function.

Discussion

- The results suggest that the auditory cortex plays a critical role in the processing of auditory information, and that lesions of the auditory cortex can result in significant auditory deficits.
- The recovery of the ABR and AEP responses over the course of 90 days suggests that the auditory system is able to adapt and recover from unilateral auditory cortex ablation.

Conclusions

- Unilateral auditory cortex ablation results in a significant decrease in auditory function, but the auditory system is able to recover function in adult rats over the course of 90 days.

References


Fig. 3. Longitudinal effect of chronic oral treatment with risperidone on mean PPI values of the experimental groups. PPI values of the vehicle (VEH) and risperidone treated (RSP) groups with a p-value of 0.05 at different moments of the experiment (n=12 each group). After 70 days of treatment, there are significant differences (*) between those groups (p<0.0013). Bars represent mean ± S.E.M.