Physiology of
the central nervous system
Part 2
Major levels of CNS regulation (Vertical organization)

1. The spinal cord
   - spinal reflexes – simple, stereotyped reaction
     - involved in control of walking movements
     - reflexes that withdraw portions of the body from painful objects
     - reflexes that support the body against gravity
     - reflexes that control local blood vessels, gastrointestinal movements, or urinary excretion.
   - receives commands from higher levels and transmits them to effectors

2. Subcortical level
   - control of involuntary and subconscious functions, emotions
     - control of arterial pressure and respiration
     - control of equilibrium
     - feeding reflexes, e.g. salivation (medulla, pons, mesencephalon)
     - emotional patterns (part of), such as anger, excitement, sexual response, reaction to pain, and reaction to pleasure
3/ Cerebral cortex

- most complex regulation: variable reaction (more neurons are involved which allows more complicated response)
- control of voluntary functions - decision making
- site of cognitive (higher) functions: memory, learning, thinking

Hierarchy in organization of the CNS

(principle of subordination)

= phylogenetically older and simple
structures are subordinated to more recent
structures (vertical functional hierarchy)
Horizontal organization - Function of the brain lobes

**Occipital lobe**
visual processing (primary projection) visual cortex

**The temporal lobe**
- auditory centres
- interpretation and association of auditory and visual information
- receptive language processing
- olfactory sensations

**The parietal lobe**
- somatosensory cortex (including taste)
- primary centre for equilibrium (psyche of the equilibrium status of the body)
- spatial processing

**The frontal lobe**
- motor processing and language production
- related to memory, emotion, and personality
- centre of decision making and executive functioning
1. Primary projection areas

   sensory - detect sensations (visual, auditory, somatosensory...)

2. Secondary areas (unimodal association areas)

   - located next to the primary sensory areas and are specific for a single modality - (therefore unimodal)
   - allow for understanding the meaning of the sensory information – shape, texture, movement, melody, etc. (sensation is turned to perception)

3. Polymodal association areas (tertiary)

   - receive information from multiple sensory and motor areas and subcortical structures (the same and also the opposite hemisphere)
   - allow for complex understanding of perceived information from different sources
Polymodal association areas

a) Parieto-occipito-temporal
   - analysis of spatial coordinates for the contralateral part of the body and contralateral external environment (based on information from visual and somatosensory areas, and vestibular system)
   - contains the Wernicke’s area - speech perception (extremely important for intelectual functions – mostly language based)
   - initial processing of visual language (reading) – feeds Wernicke’s area
   - area for naming objects – joins visual-auditory

b) Limbic association area
   (part of the temporal and frontal lobes and gyrus cinguli)
   - provides emotional drive and motivation
c) Prefrontal association area

- serves complex patterns and sequences of movements (based of afferents from parieto-occipito temporal area)
- centre for speech production (Broca’s area)
- centre for planned behaviour
- intellectual functions - understanding of moral, performing appropriate social behaviour and responses (common sense)
- suppresses instinctive behaviour - rules that are adopted during the growing-up years are seated, remembered and adequately used within the prefrontal cortex
- site of working memory
- site of problem solving
Phineas Gage
- a 25-year-old railroad worker whose personality dramatically changed after a rod pierced his skull (1848)
- lost portions of his frontal lobe

Previous to his injury, although untrained in the schools, he possessed a well-balanced mind, and was a smart businessman, very energetic and persistent in executing all his plans of operation.

- went from being a kind and mild-mannered man to rude and unrestrained
Speech centres in the brain

- speech - the ability to communicate by language (spoken, written)
- includes thinking in abstract terms (without seeing objects)

1/ Wernicke’s area
- centre for language understanding (temporal lobe)
- here the thoughts find the appropriate words as a code for the thoughts
- a lexicon that is filled with words

2/ Broca’s area (frontal lobe)
- the words are properly arranged into sentences according to grammar
- this „package“ is sent to motor areas (precentral gyrus -frontal lobe) to appropriate neurons directing the speech muscles
Mechanism of speech

(1) **Understanding a written word:**
Written word is seen by primary visual area & understood by visual association areas → which discharge to angular gyrus to appreciate the meaning of
the word → which projects to the Wernicke’s area for interpretation & formation of thoughts.

(2) **Understanding a spoken word:**
Spoken word is heard by primary auditory area → which discharges to auditory association areas for understanding the meaning → which projects to Wernicke’s area.
If the word is a name, auditory association area discharge to name area then to Wernicke’s area.

(3) **To express by written words:**
Wernicke’s area → discharges to hand skill area → which form coordinated hand movements (with help of basal ganglia & cerebellum) → which projects to primary motor area for hands.

(4) **To express by spoken words:**
Wernicke’s area → projects to Broca’s area through arcuate fasciculus → Broca’s area formulates program for vocalization & projects to face area in primary motor cortex.
Aphasia - partial or total loss of the ability to articulate ideas due to brain damage

- Broca’s aphasia (motor)
  - disfluent aphasia
  - patient can understand speech, but is unable to produce speech
  See video: https://www.youtube.com/watch?v=YgpYG5_97nE
  https://www.youtube.com/watch?v=1aplTvEQ6ew

- Wernicke’s aphasia (sensory, receptive) –
  - loss of ability to understand speech, meaning of the words
  - the patient speaks fluently, the speech is senseless
  See video:
    - https://www.youtube.com/watch?v=8Q1KNcQ8EH0
Learning
- acquisition of new information that leads to knowledge
- neural mechanism by which individual changes his/her behaviour as a result of experience

Memory
- storage mechanism for what is learned
- ability to store and recover information from the past
Memory

1/ declarative  2/ procedural (both based on changes in synapses)

1/ Declarative (explicit)
- is that what we usually mean by the word memory in everyday life
- memory for facts
- facts can be expressed in words
- WHAT?

A/ semantic memory - enables us to learn new abstract materials (like at school)
B/ episodic memory sometimes also called ‘personal memory’, or ‘experiential memory (do describe the situation that happened)

2/ Procedural memory (Implicit, non-declarative)
- memory for manual skills (driving a car, cycling, swimming)
- recalled information is expressed it by means other than words
- you can ride a bike, tie your shoelaces...
- HOW?
1. Sensory memory (iconic, echoic imprint of the reality)

- memory that allows to remember a fact approximately within initial 1 - 2 seconds after it was perceived

- outside of conscious control
  - it happens automatically and unbidden
  - results from our sensory perceptions automatically
2. Short-term memory (working memory)
- allows to retain a few pieces of information for limited time (minutes) and retrieve it during this time (mostly stimuli that are strong, important, attract attention)
  - examples: a phone number, a name of a street/person you are looking for, etc.

- operation based on reverberation circuits (circulation of action potentials through a series neurons forming a circuit)

- information in short-time memory is available only for a certain period of time, but is not retained indefinitely

3. Long-term memory
- can store much larger quantities of information for potentially unlimited duration
  - stores important info: name, address, faces of family members...

- consolidation – transfer of important information from short-term to long term memory (requires normal function of hippocampus)

- operation based on changes on synapses - the more a synapse is used, the more efficient the transmission becomes
The hippocampus

- medial temporal lobe of the brain, underneath the brain cortex

- essential for consolidation of declarative memory (to proceed from short-term to long-term memory

- without the hippocampus, new memories are unable to be stored into long-term memory
**Working memory**
- recall of a memory - information is temporarily copied from long-term memory into working memory /short term memory (frontal lobe)
Amnesia - the loss of capability to store the cognitive material for longer time
a/ anterograde – the loss of memory for events after the disturbance
b/ retrograde– the loss of memory for events prior to surgery or an accident.
Molecular basis of the long-term memory

Long-term potentiation (LTP)

- is thought to underlie memory and learning in the human brain
- is a long-lasting enhancement in signal transmission between two neurons that results from stimulating them synchronously

- the postsynaptic cell's sensitivity to neurotransmitter (glutamate) is increased
  - by increasing the activity of the synapse receptors by neurotransmitters
  - and by increasing the number of new receptors on the postsynaptic cell surface
  - by growing of new synapses
  - higher release of neurotransmitter
1. Associative learning

- learning process is based on relationship between stimuli

**A/ Classical conditioning** (Pavlovian conditioning)
- temporal association is made between a neutral conditioned stimulus and an unconditioned stimulus (*modifies reflex behaviour*)
- example: Pavlov's experiments with dogs

**B/ Instrumental conditioning** (Thorndike, Skinner)
- means association of a meaningful stimulus (reward, food) with a motor response (*modifies voluntary behaviour*)
- reinforcement and punishment are the core tools of operant conditioning
  - reinforcement – causes behaviour to occur with greater frequency
  - punishment - causes a behaviour to occur with less frequency
food presented to a hungry dog elicits an unconditioned response - salivation

sound of a bell – neutral stimulus - no response

1. Before conditioning

<table>
<thead>
<tr>
<th>Unconditioned stimulus</th>
<th>Unconditioned response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>Salivation</td>
</tr>
</tbody>
</table>

2. Before conditioning

<table>
<thead>
<tr>
<th>Neutral stimulus</th>
<th>No response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuning fork</td>
<td>No salivation</td>
</tr>
</tbody>
</table>

3. During conditioning

<table>
<thead>
<tr>
<th>Tuning fork + Food</th>
<th>Unconditioned response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuning fork</td>
<td>Salivation</td>
</tr>
</tbody>
</table>

4. After conditioning

<table>
<thead>
<tr>
<th>Conditioned stimulus</th>
<th>Conditioned response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuning fork</td>
<td>Salivation</td>
</tr>
</tbody>
</table>

- repeated ringing a bell before the food is presented – the dog learns to associate the bell with food
- conditioned stimulus (ringing a bell) causes salivation
Pressing of the left button – electric shock
- the mouse learns that it is painful, it never presses that button again

Pressing of the right button – food is available
- the mouse learns that it is pleasure, it will press that button often
Learning

2/ Non-associative – no association between events
- involves 2 mechanisms of memorizing (learning)

A/ Habituation
- repeated meaningless stimulus causes response that gradually diminishes
- the individual learns that this stimulus is not important
  (e.g. noise in the street – at the beginning it is annoying, later it is not noticed)

Molecular basis:
- progressive decrease in excitatory postsynaptic potentials (in repeated stimulation)
- presynaptic modification results in less effective Ca^{2+} channels and less mediator released for every consequent action potential

B/ Sensitization
- repeated meaningful stimulus strengthens the response
- e.g. when you notice that the speaker says "okay" after almost every sentence, subsequent "okays" become more and more annoying

Molecular basis:
- increased neurotransmitter release from the presynaptic neuron
- also a decreased permeability of K^{+} ions in the postsynaptic neuron that causes prolongation of action potentials
Electroencephalography (EEG)

- record of the brain electric activity - electrodes are attached to the scalp
- simultaneous activity of thousands of neurons is recorded
- EEG has two main characteristics
  - the frequency (expressed in Hz)
  - the amplitude (expressed in µV).
- there are four types of physiological EEG patterns (EEG rhythms)

1. **Alpha waves** (frequency: 8 to 13 Hz)
   - rhythm in an awake person with the eyes closed
   - best recorded from the parietal and occipital regions

2. **Beta waves** (low amplitude, high frequency 13-25 Hz)
   - most visible from the frontal lobes
   - produced by mental activity - the event related potentials

3. **Theta waves** (frequency of 5-8 Hz)
   - generally indicate emotional stress

4. **Delta waves** (high amplitude, low frequency 1-5 Hz)
   - in slow wave sleep (non-REM)
Principle
- short-time memory is tested with computer tests

Tests

1. **Visual memory testing by the method of recollection**
   - the screen displays 15 words for 25 seconds
   - the examined person has then to type the words that he/she can remember into the computer

2. **Visual memory testing by the method of meaningless words**
   - the screen displays 15 meaningless for 25 seconds, the examined person has to read and remember the words
   - the examined person has then to type the words that he/she can remember into the computer
   - evaluate the % of correct answers
Memory tests

Principle:
Short-time memory for 15 meaningful words will be tested by the recollection method.

Procedure:
1. read and memorize 15 displayed short words during 25 seconds
2. write words that you can remember
3. check your words with displayed words and calculate your memory score

memory score (%) = (words you could recall : 15) . 100

Result: My memory score was ..........%.
TEST 1

! STOP!

... WRITE THE WORDS THAT YOU CAN REMEMBER ...
Memory test 2

Principle:
Short-time memory for 15 meaningless words will be tested by the recollection method.

Procedure:
1. read and memorize 15 displayed short words during 25 seconds
2. write words that you can remember
3. check your words with displayed words and calculate your memory score

memory score (%) = (words you could recall : 15) . 100

Result: My memory score was ............%.
Test2

! STOP !

... WRITE THE WORDS THAT YOU CAN REMEMBER ...
Principle:
Short-time memory for 15 meaningful words will be tested by the recognition method.

Procedure:
1. read and memorize 15 displayed short words during 25 seconds
2. 30 words will be presented to you
3. write the 15 words that you can recall
4. calculate your memory score

memory score (%) = (words you could recall : 15) . 100

Result: My memory score was ...........%.
In the next slide 30 words will be presented.

Write down 15 words that you can recall
**Examination of spatial abilities**

**Spatial abilities**

- the person can rotate objects in his/her mind and deal with them in terms of turning and viewing them mentally from another angle

- Right hemisphere is important for spatial functioning in humans and is dominant for these functions.

- Men and women generally do not differ in general intelligence BUT significant differences were found in the individual subtests of specific cognitive abilities.

- Men generally achieve better scores in tests of spatial abilities, women generally outperform men in verbal tests.
A. Spatial visualization tests

1. **Cardboard folding** (complete the test in 3 minutes)
   - look at a picture showing a piece of cardboard that is to be folded.
   - choose one of the pictures A, B, C, or D showing 3D solid figures, which would be made by folding the cardboard.

2. **Box unfolding** (complete the test in 3 minutes)
   - look at the pictures showing a solid figure that is to be unfolded
   - options A, B, C and D show unfolded cardboards which would be made by unfolding the solid figures
   - choose one out of the cardboard patterns that is unfolded from lettered picture.

B. Mental rotation tests

- rotate the variants of objects in mind and decide which two of four possible options are the same as presented one

**Result and conclusions**
Perform the tests and write down your scores (%)
Cognitive training

Is aimed at training of the cognitive abilities

- in the elderly
- in patients with dementia
- in patients who have had a stroke
- in patients with brain tumours
This practical task is composed of a set of tests to train

- memory
- executive functions
- visual and spatial abilities
- attention

The training is not aimed at performing of the task within as short time as possible, its goal is to come to a correct solution by offering assistance and different clues which at the end improve the cognitive abilities of the patient.

Based on the book
Šteňová V., Ostatníková, D.: Kognitívne funkcie a ich rehabilitácia v klinickej praxi