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VISUAL PERCEPTION
VIZUELNA PERCEPCIJA

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Abstract *Visual perception is dependent on occipital cortex and dorsal and ventral visual pathway. Visual cortex processes elementary details of visual environment, and further analysis and synthesis is done in parietal region for place, and temporal cortex for object recognition. Visual attention selects which information is relevant and which is irrelevant and so allows a goal directed behavior. Visual system also mediates perception of color, spatial relations, depth perception, movement etc.*

Agnosia is a rare neuropsychological disorder, is an inability to recognize stimuli in one sense modality and can be divided to aperceptive agnosia and associative agnosia. Simultanagnosia is the inability to perceive a whole, although the recognition of individual parts is preserved and has ventral, dorsal and frontal type. The most common cause of visual hallucinations is loss of vision but can occur in various lesions of visual system. Cortical blindness is vision loss due to damage to the visual cortex in both occipital lobes. Unilateral spatial neglect phenomenon or unilateral spatial neglect is a disorder of attention control in the contralateral half of the space in relation to the brain lesion.

Key words*:* *visual perception, visual cortex, agnosia, simultanagnosia, neglect*

Sažetak *Vizuelna percepcija zavisi od okcipitalne kore i dorzalnog i ventralnog vizuelnog puta. Vizuelni korteks obrađuje elementarne detalje vizuelne okoline dok se dalja analiza i sinteza vrše u parijetalnomi regionu za mesto i temporalnoj kori za prepoznavanje objekata. Vizuelna pažnja bira koje informacije su relevantne, a koje irelevantne i tako omogućava cilju-usmereno ponašanje. Vizuelni sistem takođe posreduje percepciju boja, prostornih odnosa, opažanje dubine, kretanje itd.*

Agnozija je redak neuropsihološki poremećaj, i predstavlja nemogućnost da se prepoznaju stimulusi u jednom modalitetu čula, a može se podeliti na aperceptivnu agnoziju i asocijativnu agnoziju. Simultanagnozija je nemogućnost opažanja celine, iako se priznaju pojedini delovi i deli se na ventralni, dorzalni i frontalni tip. Najčešći uzrok vizuelnih halucinacija je gubitak vida, ali može se javiti u različitim lezijama vizuelnog sistema. Kortikalni slepilo je gubitak vida usled oštećenja vizuelnog korteksa u oba okcipitalna režnja. Unilataralni prostorni fenomen zanemarivanje ili jednostrano prostorno zanemarivanje je poremećaj kontrole pažnje u kontralateralnoj polovini prostora u odnosu na leziju mozga.

Ključne reči: *vizuelne percepcije, vizuelni korteks, agnosia, simultanagnosia, zanemarivanje*

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Organization of visual perception

Visual perception is the dominant source of information from the world around us. Visual information is processed both serial and parallel (1). First analysis of visual and spatial information is already taking place at the level of the retina. The analysis proceeds in the corpus geniculatum laterale and then in the cells of the layer IV of primary occipital cortex - area striata or area V1 (Brodmann area 17). This area lies about calcarine fissures of the occipital lobe. Each part of the retina is presented in the appropriate part of - area striata (retinotopic representation). Disproportionately large part of the V1 occupies the representation of the fovea centralis, or center of the eye's sharpest vision. The synthesis of images from both the retina occurs in complex cells of the II, III, V and VI layers of the visual cortex is, where one eye is dominant in individually varying degrees (2).

In the primary visual cortex neurons the processing of information takes place as in sets of selective spaciotemporalnih filters specialized for spatial frequency, orientation, movement, direction, speed and various other features. After the first 100 milliseconds the primary cortex neurons process more complex, more global aspects of the visual scene. Visual information in the primary cortex neurons is encoded as a local contrast and further processed in extrastriate visual fields marked as V2, V3, V4 and V5 (3).

Area V2 is prestriate cortex. It is the first zone of visual associative cortex. It is organized in retinotopic left and right and upper and lower quadrants, and so completely represents visual environment. Neurons in this part of the cortex respond to orientation, spatial frequency and color but also to the more complex aspects such as contours or pertaining to the figure or background. Prestriate cortex sends information to several visual centers but also back to V1.

Next in the hierarchy is area V3. It is possible that it is divided into dorsal and ventral areas. Dorsal V3 (BA 19) is the dorsal part of the path that conveys information to the parietal cortex. It is believed that it participates in the perception of motion. Ventral part of V3 is associated with lower temporal cortex.

Visual perception takes place in the continuity of the registration of simple features of visual stimuli such as brightness, angle, length, curvature, motion, size, color, etc., to the whole perception, spatial relations and recognition (3). Complex visuoperceptive processes are complex visual discrimination, distinguishing figure from background, visual synthesis, face recognition, and related areas of visual construction and visuospatial functions. Visual perception includes also reading and writing. The brain has records of previously seen images from which it can recognize objects, persons, letters, and more.

Visual area V5 is also called middle temporal (MT) visual area and is part of the extrastriate visual cortex. The main role of V5 is the perception of motion, visual integration and control of eye movements. Area MT has rich connections with other visual areas, lateral geniculate nucleus, the lower pulvinar, the frontal eye field and parietal lobe. According to the classical neuropsychological model recognition takes place in two stages: **apperception** (conscious perception of a whole composed of individual elements) and **association** (connection of the perceived objects with the experience that gives meaning to it) (4).

Since the eighties of last century, it became clear that the visual information is analyzed in both serial and parallel manner. Two paths have been isolated: the dorsal and ventral (5).

Dorsal route spreads from occipital lobe (area striata, through V2, dorsomedialy and in area V5) to the lower parietal lobule. This route is involved in visual perception of spatial relationships and representation of space, and is also referred to as "where" road or path for control of action - a pragmatic one. It perceives the movement, location of objects and controls visuomotor coordination.

Ventral path leads from the occipital lobe (again first area V1, then area V2 and finally area V4) to the lower temporal cortex. Object recognition is taking place in the occipital structures and then in the lower temporal cortex. Therefore, this path is called a "what" or perceptual-semantic route.

Some authors propose three different systems: dorso-dorsal (control of action), ventro-dorsal (perception of space, representation of action, and recognition of action) and ventral (object recognition) (1). All three systems are associated with the respective frontal areas.

Intraparietal sulcus separates the upper from the lower parietal lobule. Upper lobule is part of the somatosensory system and receives information from the primary sensory cortex, specifically regarding proprioception, and also receives visual information and sends impulses to the primary motor cortex and dorsal premotor cortex. The lower parietal lobule also has input from the somatosensory cortex and majority information from the visual association fields and auditive cortex. Thus, the lower parietal lobule integrates auditory, visual and somatosensory stimuli in the perception of the outside world and the actions in it. It projects to the ventral premotor cortex and prefrontal areas.

Unilateral spatial neglect occurs in lesions of the lower parietal cortex, usually right, and parts of the frontal cortex (BA 6, 8 and 45). Neglect can selectively hit extrapersonal and peripersonal space or both.

According to the Benton (6) in the domain of visual perception can be distinguished: 1. Fine visual discrimination: analysis of size, length, curvature, brightness (right posterior parietal lobe); 2. Distinguishing figure from the background (so-called mixed and matched figures) (mostly right parieto-occipital region, this function is compromised in other focal lesions, especially with aphasia); 3. The synthesis of visual information: simultangnosia (understanding of complex thematic images) and identification of incomplete pictures. Disruption of this function is called simultanagnosia and has been observed in many disorders (dementia, left and bilateral occipital lesions and damage to the frontal lobe)

Lateralization of the lesion is not always decisive because visuospatial discrimination tasks can be solved both by visuospatial and verbal strategy, which depends on individual experience and requirements of the task (7). There are many objects which occupy different places in space, making a sensory environment very complex. This makes necessary a mechanism for selection of objects or locations based on visual attention. Cerebral location of this function is the posterior parietal cortex, i.e. upper parietal lobule/precuneus bilaterally (8). Selective attention can be based on the space and on the objects. It seems that sensitivity for objects is higher, based on input from the occipital region and relevant retinotopic area. Thus, the left parietal cortex would be particularly sensitive to the characteristics of the object. Posterior parietal cortex shifts attention from one location to the other in the surrounding area.

Visual attention selects which information is relevant and which is irrelevant and so allows a goal directed behavior. Detection of the target is facilitated if it was previously hinted at. Inhibition also surrounds the focus of attention.

Visual perception of objects is based on a synthesis of information from different senses (multimodal representation of objects) and is mediated by anteromedial temporal lobe of both hemispheres and to a lesser extent the left temporal sulcus (rear part) and middle temporal gyrus (9).

Perception of color

Perception of color depends on the presence and intensity of various wavelengths (BA 17, 18, 19) (3). Automatic color constancy is mediated by fusiforme gyrus. The color of objects is the function of the lower temporal and frontal cortex). Constancy of color perception depends on the neural mechanisms that compensate for various degrees of brightness in order to maintain the constancy of color perception. Disturbance of the constancy of color perception is crucial for cerebral ahromatopsia.

Visuospatial functions

In processing of spatial information vast brain areas are involved (3). Cingulate cortex mediates motivational mapping of extrapersonal space. Posterior parietal cortex is responsible for the sensorimotor representation of significant external events. Frontal eye fields are the dominant areas of attention control. Also, in visuospatial functions are included subcortical areas, striatum and thalamus. Areas of integration of spatial information receive impulses from all areas of primary and secondary sensory (associative) sensory cortex.

Stereopsis

Stereopsis is based on evaluation of the depth according to binocular visual information with disparity of two retinal images (3). Responsible areas for this function are the visual cortex (Broadmann areas 17 and 18, and parieto-occipital cortex) bilaterally or on the right, but also other areas of cortex. Important clues for assessing the depth of distant objects are the angular velocity, the relative sizes and colors.

Coordinate systems can be classified as: 1. Related to the observer (left to right, near-far above-below), 2. Linked to object - its own spatial coordinates and 3. Related to the environment - relationship with the environment in terms of geographical and gravitational coordinates. Of great importance is attention management with the right hemisphere directing attention to the whole space and the left hemisphere controlling attention in the contralateral (right) half space (10). That is the reason that hemispatial neglect is mainly observed in right-sided lesions.

Visual agnosia

Agnosia is a rare neuropsychological disorder that manifests as an inability to recognize stimuli in one sense modality, and is not caused by elementary sensory disturbance, general cognitive deterioration, disorders of attention, awareness, anomia or lack of knowledge of the given stimulus (lower level of education, cultural factors, etc.). Agnosia is a word of Greek origin, from word gnosis meaning knowledge, the name coined by Siegmund Freud in 1891 (3).

In focal lesions, agnosias are as a rule limited to one sense modality (visual agnosia, auditory agnosia, tactile agnosia, etc.). The patient can not recognize objects that were previously in his experience, but only through affected sense. For example, a person with visual agnosia can recognize the object by touch. Agnosia is a rare disorder in pure form often there is some damage of the elementary stages of perception. This is why some authors still deny the independence of this phenomenon. The degree of non-recognition or misrecognition is not always the same.
Perception, and therefore agnosia can be divided, as mentioned before, into two stages and hence two types of agnosia as suggested by Lissauer in late 19th century (11). **Aperceptive agnosia** is a disorder of the synthesis of the observed elements of information into the whole and **associative agnosia** is a disorder where linking elements into a whole is possible, but lacks connection with previous experience (i.e., can not recognize a whole). A patient with aperceptive visual agnosia can not draw a picture of the object because he can not perceive the whole and does not recognize or can not choose from the number of objects while the patient with associative visual agnosia can draw the picture of the object and can choose the appropriate object from the group of objects but can not recognize it and connect the perception with the previous experience.

Visual agnosia is usually associated with lesions of the left medial occipital lobe while concomitant damage of the splenium of the corpus callosum. Visual agnosia can be divided into prosopagnosia, color agnosia, object agnosia, agnostic alexia, picture agnosia and simultanagnosia (12).

Simultanagnosia

Simultanagnosia is the inability to perceive a whole, although the recognition of individual parts is preserved or the impairment of simultaneous recognition of two or more things. Describing the thematic pictures is fragmentary and they can not understand what the picture represents. Patients are blocked by the details in the center of gaze and do not try to search the visual environment for further information. The movement and distraction hinder visual perception. Simultanagnosia has various degrees. Three types of simultanagnosia (13).

Ventral simultanagnosia is observed in lesions of the left occipito-temporal area and is considered to be due to slow processing of visual information. Patients with this type of simultanagnosia can not identify more than one object at a time, although they can see more than one object. They do not bump into the objects that are on their way. They can observe only the fragments of the complex picture without understanding the whole. This type simultanagnosia impairs ventral (temporal) visual way (“What pathway?”). This type of lesion leads also to the object agnosia, prosopagnosia, alexia and color vision disorders (cerebral achromatopsia).

Dorsal simultanagnosia occurs in bilateral parieto-occipital lesions. It represents inability to discriminate more than one object at a time (the biggest single object that carries meaning.) They also have difficulty reading and arithmetic (14). The disorder is mostly related to attention and spatial localization of visual stimuli. They strike into multiple objects that are on their way so they look like they are blind. This type of simultanagnosia is caused by damage to the dorsal (parietal) visual pathway ("where? pathway") where there may arise other visuospatial disturbances (disturbances of perception of movement, inability to locate objects in space, poor assessment of distance, orientation and size). This disorder can occur as part of Balint's syndrome.

Frontal lobe simultanagnosia arises because this lobe also has a role in processing visual information, visual attention and visual working memory. Ventromedial prefrontal cortex is associated with the ventral visual information processing, and the dorsal prefrontal cortex with the dorsal visual information processing pathway. Thus, the frontal cortex is superior to other visual areas and makes decisions about which objects are relevant and which irrelevant (distractors). Visual attention is focused and the experience of integrity of the visual space is more likely a result of a series of quick successive views, then simultaneous observations.

Balint's syndrome (15) occurs in lesions of the upper parietal lobulus (above sulcus intraparietalis) bilaterally and consists of (16): 1. **simultanagnosia** - surroundings seems to them like a chaotic series of individual objects; 2. **optic ataxia** - inability to direct motion by the visual sense. These patients have no problem when the target is in the fovea, but when the target is in the periphery of the visual field. These patients can not assess the distance and depth of the space. Unilateral lesions may cause contralateral, ipsilateral or bilateral optic ataxia; 3. **acquired oculomotor apraxia** - a disorder of visual attention with the defect of visuomotor search of the field of vision - patients can not initiate saccades – so called psychic paralysis of gaze.

Balint's syndrome occurs most often in biparietal posterior lesions. However, similar clinical manifestations can be seen in bifrontal lesions, occipital associative cortex lesions, parietotemporal area, and possibly pulvinar (13). Etiological factors are multiple (17) (13).

Associative visual agnosia

Patients with associative visual agnosia can perceive a whole visual stimulus as proved by successful copying or matching, but the recognition of object in the visual modality is impossible (18). As a rule, it is more difficult to recognize pictures than real objects. Given stimulus can be recognized by touch or sound. Agnosias are unimodal disorders and depend on the complexity of visual stimuli. In the worst cases object agnosia can occur when patients can not recognize even real objects, and in mild forms patients can not be able to identify only masked or overlapped images. Object recognition is a function of ventral left temporal region. Frequently, however, there are diffuse bilateral lesions.

Visual object agnosia

Visual object agnosia is a disorder of the generic identification of objects: these patients do not recognize any class of objects (e.g. a person as a person, the car as a car). The most common cause of this disorder are bilateral infarcts in the posterior cerebral arteries irrigation area. Types of object agnosia are aperceptive (BA 17, 18, 19) and associative (11). Yet these two versions differ in level of representation: aperceptive is the level of primitive representations or 2.5 D representation and associative - 3D level representation and its relation to semantics. Associated signs include: alexia, anomia, amnesia, achromatopsia, prosopagnosia.

Prosopagnosia

Prosopagnosia is the inability to recognize faces. Prosopagnosia can be divided into aperceptive, associative, and amnestic type. In most cases category recognition is preserved. Memory of the faces is completely damaged and such patients can not recognize previously familiar faces and they can not remember the new one. The face is the most common non-verbal visual stimulus (6). Prosopagnosia can be divided into agnosia for familiar faces and a disturbance of discrimination of unknown faces. Agnosia for familiar faces can be seen in retrorolandic right hemisphere cerebral lesions, mainly in the lower occipital lobe. Frequent are also bilateral lesions. Agnosia for familiar faces may be accompanied by agnosia for graphical symbols, spatial disorientation, color agnosia, topographical memory disorders, constructional apraxia, dressing apraxia, hemianopsia and dextral spatial alexia. Agnosia for unfamiliar faces occurs in right-sided damage. These people are not able to discriminate and analyze the characteristics of unknown persons.

Visual hallucinations

The most common cause of visual hallucinations is loss of vision. Charles Bonnet syndrome (described in 1760) is based on release phenomenon with simple or complex hallucinations without psychiatric or organic substrate (19). It may be flares, lines, shapes, objects or complex scenes (like sleep). Most often it is physiological response of visual cortex to the loss of vision in both eyes. This type of visual hallucinations lasts seconds, minutes or permanently.

Epileptic visual hallucinations can be simple in striate cortex seizures (20). Complex hallucinations occur with focus in area 19 and in the temporal lobe. Sometimes these hallucinations build on the other (primary) phenomena due to the spread of epileptic activity in the cortex, and in a reverse case, once the activity is spread from the area that mediate visual information to other cortical areas nonvisual symptoms can occur. Migraine attacks may be preceded or be accompanied by a simple visual phenomenon such as spots, zigzag lines, and shimmering scotomas with edges that can increase and/or move in the visual field or can have form of fortificatio spectra. Peduncular hallucinations are of mesencephalic origin. They are complex, detailed hallucinations. Usually this phenomenon is accompanied with sleep inversion.

Visual distortion can exist in form of micropsia of macropsia with diminution or augmentation of pictures respectively (20). Metamorphopsia designates distortions of observed visual scenes and objects.

Cortical blindness

Cortical blindness is vision loss due to damage to the visual cortex in both occipital lobes and exhibit great variability. Lesions can affect not only cortical areas but also often optical radiation. Antonov's syndrome is a specific anosognosia (denial of deficit) for cortical blindness. People claim to see though blind and can not be convinced by facts. Patients can confabulate their visual environment. The most common etiology is vascular (21).

Etiology of cortical blindness is diverse: stroke, hypotension, hypoxia, meningitis, encephalitis, mitochondrial encephalopathy, leukodystrophy, prion disease, subacute sclerosing panencefalitis, multiple sclerosis, hypoglycemia, poisoning with carbon monoxide, uremia, cytotoxic drugs, mercury, lead, ethanol, heroin, brain trauma, cerebral edema, porphyria, epilepsy, electrocution, radiation, snakebite, and more.

Neglect phenomenon

Unilateral spatial neglect phenomenon or unilateral spatial neglect is a disorder of attention control in the contralateral half of the space in relation to the brain lesion. Neglect occurs in the perceptions in the contralateral half of space, direction towards that side and motor activity in the half space. Right hemisphere lesions are much more likely than the left sided lesions (16). Between one and two-thirds of patients with right sided focal damage exhibit this disorder. Neglect is commonly found in both ischemic and hemorrhagic brain infarcts, in the right perisylvian area, usually involving lower parietal lobe (angular gyrus and supramarginal gyrus) and/or temporo/parietal intersection, parts of the dorsolateral premotor frontal cortex, thalamus, midbrain and basal ganglia and frontoparietal connections (22) (23). Neglect occurs also in brain tumors.

Neglect encompasses all three domains of space: the space of his own body, gestural space (which can be reached by hand) and visual (which is also acoustical) that refers to the space that can not be reached immediately. Neglect does not have to include all three areas of space. So there can be only a personal but not extrapersonal neglect and vice versa. These patients do not dress the left half of the body, do not shave the left side of the face, do not eat from the left side of the plate, do not read the left half of the sentence, and write and draw more in the right hemispace.

Unilateral neglect be seen also on the motor plan mostly as motor limb akinesia with absent spontaneous movements (pseudohemiparesis). Neglect can reflect programming deficit in prefrontal lesions or perceptual deficit of parietal lesions. There is some evidence that under normal conditions there is a rivalry between the hemispheres: the left hemisphere tends to draw attention to the right half of the space, and the right hemisphere to the left (23). The application of dopaminergic agonists (e.g. bromocriptine) showed some effect in alleviating neglect (24). Noradrenergic agents (e.g. guanfacine) have proved useful in reducing partial neglect (25).

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