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EYE MOVEMENTS AS THE WINDOW INTO VISUAL ATTENTION MECHANISM AND SITUATION AWARENESS

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SUMMARY: *Eye movements are one of the best neuropsychological indicators of higher cognitive and mental functions. Especially, working memory system is closely linked with visual attention and, consequently, occulomotor processes. Some theoretical models are discussed together with empirical evidences from own experiments, and in conclusion original unified model of working memory and visual attention is proposed*
KEYWORDS: *Visual Attention, Working Memory, Eye Movements*

Purpose of the work is to analyze the involvement of higher mental functions (especially working memory mechanisms) in the processes of eye movement. To sum up theoretical models and empirical data, it should be noted that among the psychological processes responsible for visual perception (described in the literature as visual attention), we distinguish three groups. This is the visual settings control, distinguishing objects in the visual field and detailed cognitive processing of objects in central vision. These three processes are schematically presented on figure 1.

Only the central vision and has a sufficient acuity and (more important) the ability to perceive conjunctions of features and “access” to the mind, what allows to compare the patterns with perceived objects and recognize them. That’s why in visual perception eye movements are so important- they are allowing analysis of more and more new objects with central vision. Moving eyes on the object is preceded by highest priority assignments - among many objects in a field of vision extends to the fore. Assign the priority may depend both on the characteristics of the object itself, as well as the subject’s intention of seeking specific items.

The highlight of the diagram is so slightly mysterious “visual mind”, making the analysis of cognitive material perceived by the central vision, evaluating the validity

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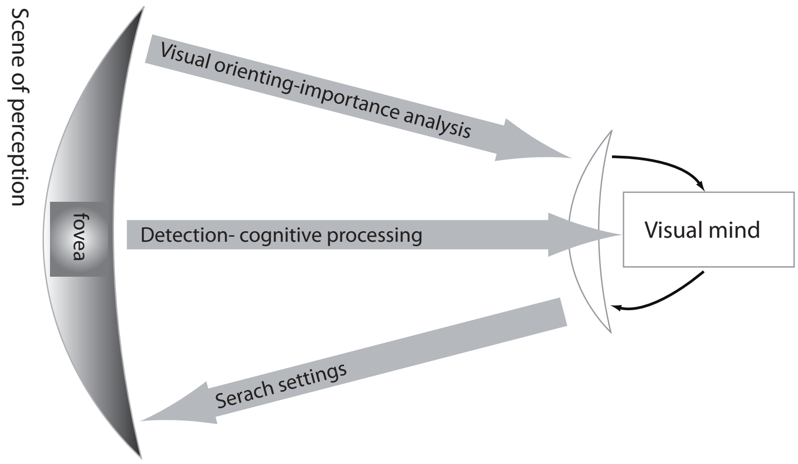

Fig. 1. Three components of visual attention.

of the emerging distinct objects, and setting the search criteria (sensitizing peripheral perception of specific features). The main reason for writing this work was an attempt to decipher the structure, examine its relationship with eye movements, and relation to higher mental processes organizing of human activity. Visual mind is nothing other than a function of the broad conception of working memory. Although it is difficult today to present a satisfactory model of working memory, but in perspective of recent Baddeley's work [1], [2], together with Norman and Shallice [3] classic SAS model, one can assume the following concept.

Working memory is a complex structure of slave systems and one central mechanism. Slave systems in perspective f current empirical seem complicated system of interrelated structures. Certainly phonological loop is a construct real and well-proven in experiments, while visuospatial notepad in the light of current data it is better to describe as two independent structures - spatial memory (stores information about the location of important objects, responsible for spatial orientation), and visual memory (responsible for memory images). As a similar slave system one can also describe prospective memory (that holds the information needed to plan for the immediate future), although the overall model incorporating this component has not yet been formulated. Central mechanism, regardless of the type of tasks is engaged when the tasks are difficult, complex, new and engaging the emotions. It is responsible for control activities, which often, though not always, associated with conscious introspective subjectivity.

Eye movements per se do not have to absorb the central mechanism resources. In many experimental situations (especially in the frequently system in our study, the gap/overlap paradigm) eye movement may be of a purely reflexive. In other situations, in varying degrees and in some aspects both the direction and time course of motion are intentionaly controlled (ie, selection of an object to a cognitive analysis). Particularly strong are the central mechanism of eye movements control in the antysaccade task, when subject is asked to direct the eye in the opposite direction to the actual abrupt stimulus. Eye movement control may rely on the lengthening and shortening fixation on object, but may also affect the direction of the movement. In that case the matter appears more complicated because the control may not only concern the mapping of priorities (and thus determine which objects in the visual field are "worth" a thorough analysis) but the also direction of eye movement, that is not determined by the map of priorities, as evidenced by the ability to perform antisaccades.

In some experiments [4] shortening of the saccades reaction times were observed, when additional tasks absorbed central resources, but were not related to visual processing. In this situation, the eye movements could be easily automated. In experiments, these additional tasks were related to decision-making, verbal memory workload, and control of hand movements. None of the additional tasks, therefore, had no connection with the receipt of information, but only with the memory (defined as the load on phonological loop), or executive control. Thus, eye movement does not need to be controlled by a central mechanism, and if necessary, (in the case of the central mechanism overload) control of eye movement may be managed with fewer resources. This explains the paradoxical effect of reversing the Sternberg rule in experiment - increasing memory load resulted in a stronger involvement of the central mechanism, fewer and fewer resources remained to control eye movements, and - consequently - they were performed more automatically (and therefore faster).

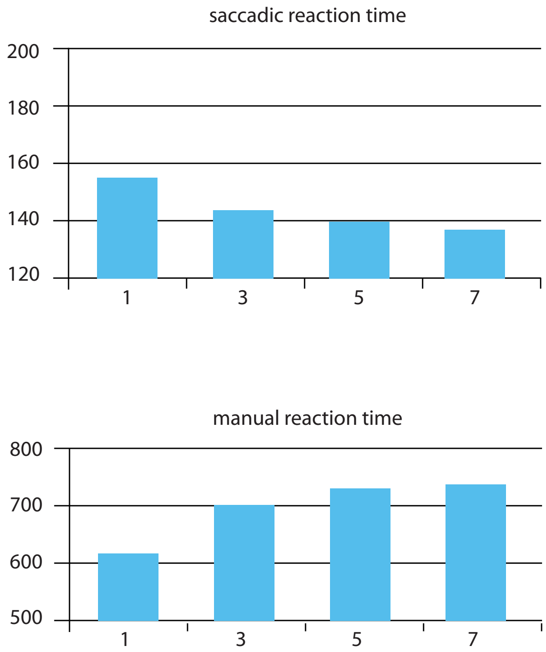

Fig. 2. Saccadic and manual reaction times as a function of verbal memory workload.

Other experiments results have shown that if the additional task involves spatial memory, saccadic reaction times elongate. Thus, the mechanism described above (automation of occulomotor response in situation of task overload) in this case does not work. Perhaps this is because the execution of eye movement requires the participation of the working spatial memory, when this it is involved in creating visual attention maps. In a situation where two tasks compete for working spatial memory resources, necessary to drive both eye movements and storage of spatial memory material, both tasks are performed slowly and with a loss of quality (fig. 3).

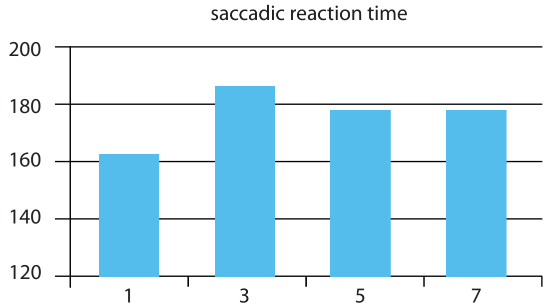

Fig.3. Saccadic reaction times as a function of spatial memory workload.

In the model proposed by Itti and Navalpakkam [5] "task relevance map" is a construct that describes assigning higher priorities to objects associated with the currently executed task. This construct appears to be redundant in the context of above studies. It can be assumed that this is indeed the priorities control, in other words, the task-dependent perceptual system settings, controlled directly by working memory. This definition simplifies the model describing the top-down and bottom-up processes of visual prioritizing.

These findings and reflections allow to expand preliminary model, shown in figure 1. Especially the "Visual brain" can be reduced to well-known constructs of working memory. Thus, the information from the peripheral visual field is formed in the first saliency map, reflecting the objective, physical brightness of the individual elements of the visual field. This information is also passed to the spatial working memory, which uses it in constructing the current situational awareness.

Information from the central field of view inputs directly into the working memory. This is where there is a core part of the "visual mind". Phonological loop can now process semantic information from reading processes. Probably after the decoding semantic information related to perceived objects, pictures or pictograms are processed in the same way. Working procedural memory (prospective), using the foveal information, monitors the adequacy between planned and actual task run. Visual (pictographic) memory processes shapes, which are not easily to verbalize. Contrary to those effects, use of foveal information by the spatial working memory is indirect. Spatial tips (eg arrow) are decoded the visual (pictographic) memory, and then only affect the spatial perception settings. Involvement of the central mechanism in these structures depends on the novelty and complexity of tasks and visual material.

Control settings depends on the spatial working memory, sensitizing perceptual system to stimuli in a certain sector of vision and visual (pictographic) working memory, sensitizing to the colors and shapes. Schematically the relationship between the perception and working memory is presented on figure 4.

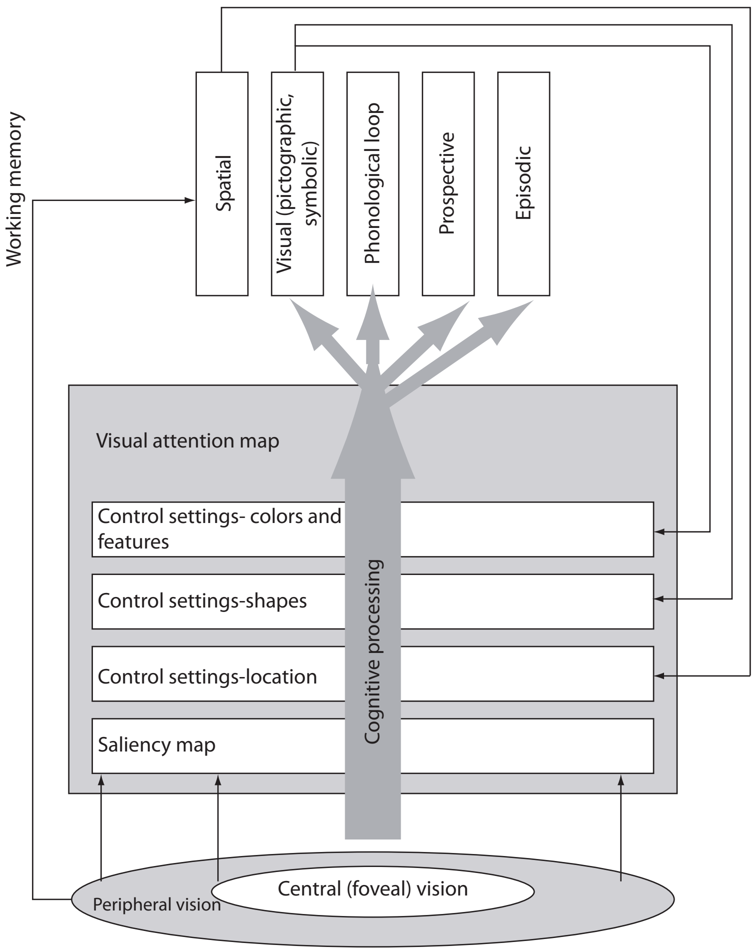

Fig. 4. Relationship between working memory and perception

Above presented schematic model of relationship between working memory and perceptual system can give an insight into situational awareness problem. In aviation, situational awareness demands not only spatial awareness, but also system and task awareness [6]. In any problematic conditions (disorientation, IMC) overload of working memory structures may suddenly appear. Presented model suggests, that spatial disorientation (overload of spatial working memory is the core of this problem) may be connected with hyperintensive cognitive processing, locking most of the central executive resources.

Cognitive tunneling appears in this model as a problem of inadequacy of visual attention map. Subject, due to domination of top-down factors, can easily mispercept important unexpected objects. So called bolstering- tendency to seek information confirming right of chosen action option- can be described as inadequate and inflexible attentional control setting. Above explanations need to be confirmed in direct experiments.

Cognitive science is not only the tower of glass, without connections with aviators training and selections. Situational awareness bases on real brain structures, and its functions can be tested in psychological diagnosis and trained in special procedures. Understanding of brain hardware and psychological software of our mind allows to develop better, more effective training. Psychologists are now able to assess cognitive dysfunctions with better reliability and validity, what implies better quality of psychological care and flight safety.

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