Role of Saccadic Eye Movements in Cognitive Processes

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Using specially developed tests we studied the processes of prediction of the appearance of letter sequences and simultaneously recorded saccadic eye movements. It was found that the number of saccades increases with increasing test complexity, which is probably related to the necessity to process more complex and capacious information.

Key Words: *saccades; cognitive processes; prediction; neurophysiology; psychophysiology*

Numerous studies showed that saccadic eye movements accompany cognitive processes (attention, memory, and thinking) and, vice versa, cognitive processes are often suppressed without saccadic eye movements. Functional and anatomic overlapping of brain pathways and structures (frontal cortex, parietal cortex, basal ganglia) enables planning, programming, and decision making on the one hand, and regulation of saccade generation, on the other [6]. Various methods of rehabilitation of brain structures involved in the regulation of movements in patients with cognitive and motor disturbances improve both the quality of movements and cognitive processes [11]. Despite the fact that these processes, cognitive (psychophysiological) and saccadic (neurophysiological), are closely related, the role of this interrelation is still poorly studied. Since control of eye movements and regulation of this process is executed at various level of the brain, saccadic activity can be used as reflection of dynamic processes in the brain for evaluation of various forms of cognitive activity, including prediction of events.

Here we evaluated possible role of saccades during prediction of the appearance of certain events, a form of cognitive activity.

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MATERIALS AND METHODS

The experiments were performed on 12 healthy adult volunteers (22-59 years) after preliminary psychological testing by MMSE and UPDRS. According to Prognosis-1 method [4], the experimenter presented cards with letters A or B to an examinee (card by card according to a certain sequence unknown for the examinee). The examinee predicted the appearance of the next letter, thus determining the order of letters in this sequence. After each answer the examinee was informed whether or not the predicted letter was correct. Three sets of cards (3 tests) were used. The first set included a sequence (block) AB repeated 10 times, *i.e.* consisted of 20 cards. This start up test was not then analyzed. The second test included a block ABB repeated 10 times, *i.e.* consisted of 30 cards. The third most complex test included a block BABBA repeated 12 times, *i.e.* consisted of 60 cards. The order was disclosed, if the examinee correctly predicted each next letter in three consecutive blocks. After presentation of letters in all three sets, the examinee was asked to reproduce the sequence of letters in each set. All errors (during prediction and reproduction) were recorded [3]. Saccadic eye movements were recorded using a standard electrooculography method (EOG) at rest and throughout the experiment. Active electrodes were positioned at the temporal edge of the orbit of each eye, indifferent electrodes were located on the lobe of the corresponding ear. This location of electrodes allowed recording of horizontal saccades and horizontal components of all other saccades. EOG signals from each eye were amplified to 1 V with differential amplifiers (2.2 sec time constant, 250 Hz pass band) and recorded using a Bruel & Kjaer magnetic recorder (in a direct current regimen). To exclude saccades made by the examinee during viewing of the card, the experimenter pressed a button at the beginning of card demonstration and released it at the end of demonstration; the marked artifact period was not then analyzed. After the end of the experiment, the data from magnetic recorder were input (fragment by fragment) into a computer, the total number of saccades in each test was counted visually on the computer monitor. Since the tests had different duration, the number of saccades per 1 sec was analyzed for data standardization. The data on saccades and mistakes were processed statistically using nonparametric Wilcoxon and van der Waerden test.

RESULTS

The data obtained in different times in previous studies with the use of Prognosis-1 method on a larger sample (>1000 examinees) [5] revealed 4 types of human prognostic activity differing by the number of erroneous predictions, distraction errors, and reproduction of letter block sequence. It was demonstrated that high and low efficiency of prediction corresponded to ≤7 errors and ≥12 errors, respectively. In most cases, examinees with high prediction efficiency (type I a and b, type II a) [5] were characterized by high efficiency of other cognitive processes: retrieval of letter sequences and high concentration (low number or absence of distraction errors). On the contrary, examinees with low prediction efficiency (type III b, type IV a and b) were characterized by insufficient memory and concentration (great number of retrieval and distraction errors). At the same time, the number of errors increased with increasing test complexity in examinees with not only high, but also medium and low prediction efficiency.

In our experiment, the mean number of saccades in the total sampling over the recording time was 21.1±3.0, *i.e.* 0.12 per second. During prediction of the first simple block, the total number of saccades (43.4±2.3) and the number of saccades per second (0.47±0.08) significantly increased compared to that in wakeful individuals at rest (21.2±3.0 and 0.12±0.06, respectively). During performance of the other two tests, the mean total number of saccades made by the examinees (142.4±27.9 and 195.3±36.7) and the number of saccades per second (0.63±0.09 and 0.70±0.11, respectively) also significantly differed ($p<0.05$) from those recorded in wakeful individuals at rest, *i.e.* the total number of saccades and the number of saccades per second significantly increased with increasing the complexity of the prediction task (from test 1 to test 3, Fig. 1). The results of retrieval task after performance of all tests were similar, the only exception was that the total number of saccades and the number of saccades per second were lower than during prediction task (Fig. 2). This can be explained by different mechanisms of solution of prediction and retrieval tasks: information recording in the first case and information retrieval in the second case. At the same time, the number of errors during prediction and retrieval similarly increased with increasing test complexity: 1.7±0.3, 4.0±1.1, and

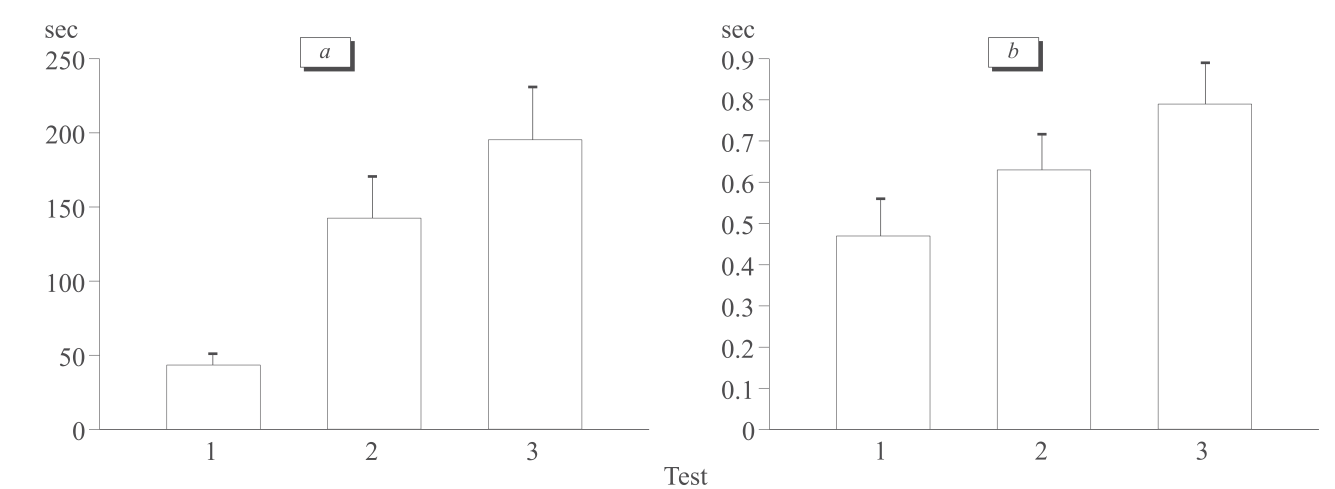

Fig. 1. Total number of saccades (*a*) and number of saccades per second (*b*) during performance of prediction tests. Here and in Figs. 2 and 3: all differences are significant at $p<0.05$.

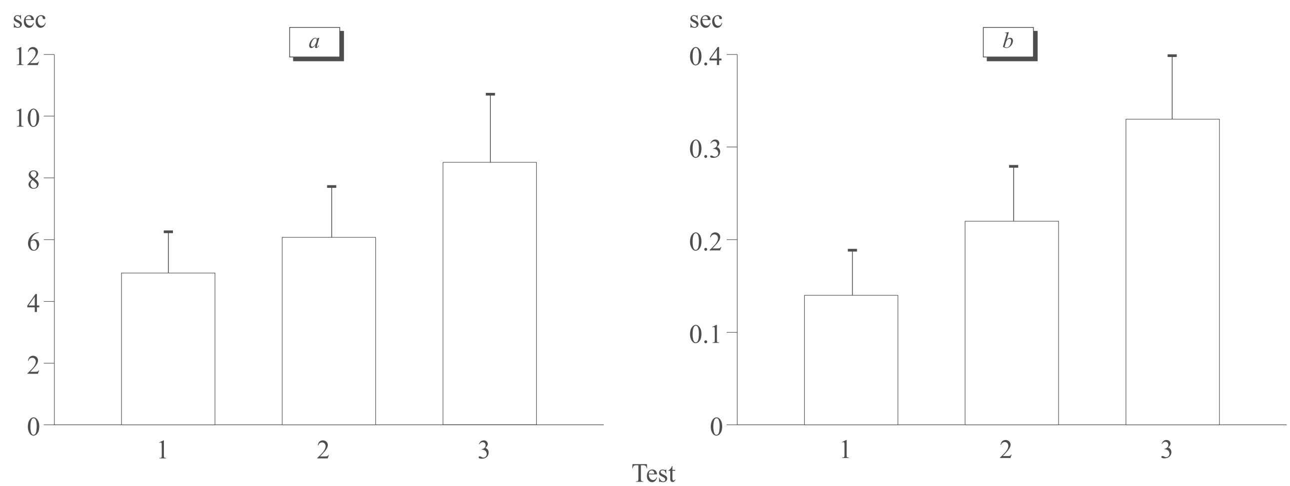

Fig. 2. Total number of saccades (*a*) and number of saccades per second (*b*) during retrieval of letter sequence.

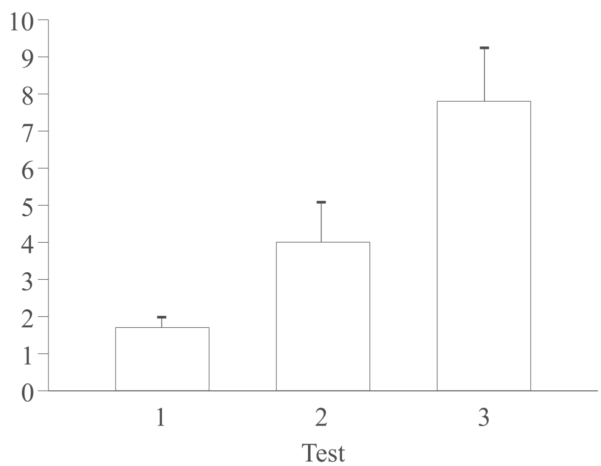

Fig. 3. Number of errors in prediction tests.

7.8±1.4 in tests 1, 2, and 3, respectively (Fig. 3). Thus, we have good concordance between the data obtained in studies of cognitive processes on the one hand, and during recording of saccadic eye movements and number of errors, on the other. The increase in the number of errors with increasing test complexity is a natural and expected phenomenon, but the increase in the number of saccades is not. It is most likely that there are no cause-effect relations between these facts.

Analysis of our findings showed possible mechanisms responsible for cognitive activity of humans, prediction of events in the environment. During visual perception, recognition of visual images, and reading, the role of saccades is related to merging of image fragments into the comprehensive whole, which occurs at the moment of vision suppression during saccades [2,9]. At the same time, saccades suppress cognitive processes requiring concentration [7] probably due to the same mechanism.

According to our data, the more complex is the prediction test, the greater number of saccades per time units was recorded during its performance. This suggests that greater information volume requires higher number of saccades for its processing.

In light of this, we concluded that during cognitive activity, similarly as during viewing of the scene or during reading, saccades appear for creating time intervals (between saccades) for perception and processing of information (cognitive fragments) and its memorization. These fragments are merged into the integral idea leading to decision making. As for retrieval of the letter sequence from memory (test 3), saccades are also necessary for this process. The lower number of saccades during retrieval compared to that during prediction suggests that memorized information after its analysis and synthesis is processed and purified from odd and unnecessary details, but still requires merging of information fragments into the integral idea (cognitive output).

The detected interrelationship between complication of the cognitive tests and the number of saccades can be used not only for studies of cognition processes, but also in clinical practice for early diagnosis of pathologies associated with parallel impairment of motor and cognitive functions (Parkinson's disease, Huntington chorea, schizophrenia, *etc.*) and for controlling aging processes [13, 14]. It was demonstrated that cognitive processes, including visual and spatial attention, working memory, planning, and decision making are considerably impaired in these pathologies [8,10], the parameters of saccades are also disturbed (increased saccade latency and duration, multisaccades) [1]. The following elements of the process should be analyzed: saccades and intervals between saccades, when integration (merging) of information occurs.

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