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Eye Tracking as a Tool for Medical Diagnosis

Evgeny Yu. Shelepin[1*], **Ksenia A. Skuratova**[1], **Polina A. Lekhnitskaya**[2], **Konstantin Yu. Shelepin**[1]

[1] Pavlov Institute of Physiology, Russian Academy of Sciences, Saint Petersburg, Russian Federation
[2] Kazan (Volga Region) Federal University, Kazan, Russian Federation

[*] Corresponding author: ShelepinEY@infran.ru

Abstract

Introduction. The transition to personalized, predictive and preventive medicine, high-tech healthcare and health-preserving technologies is one of the priorities of scientific and technological development in the next decade. The possibility of using eye tracking for medical diagnostics meets this priority. **Eye tracking as a tool for medical diagnostics.** Using eye tracking, disease detection is based on the main types of eye movements: fixations, saccades and nystagmus. However, protocols that allow a comprehensive assessment of the patient's condition have not been fully validated. The purpose of the current review is an attempt to consider studies in the Scopus, Web of Science, and RSCI databases regarding the utilizing of eye tracking as an addition to the diseases and disorders diagnosis, and to outline possible trajectories for the development of this method in the field of medicine. The article provides examples of the use of eye tracking in dementia, mild cognitive impairment, Alzheimer's disease, schizophrenia, schizotypal and delusional disorder, mood disorder, attention deficit syndrome, the consequences of a stroke, and head injuries. **Results and discussion.** Eye tracking is characterized by objectivity, brief and stress-free observation of a patient, the ability to simplify the tasks presented with high diagnostic accuracy, finding a simulated disorder, supplementing existing tests, searching for latent signs, higher sensitivity compared to some neuropsychological tests, the ability to dynamically switch between tasks. As a prospect for developing diagnostic protocols based on eye tracking, it is possible to: use existing paradigms for conducting eye tracking studies, combine new paradigms with existing neuropsychological tests and methods, inherit the basic principles of examining the patient's condition, and build data analysis models. Validation on a wider sample and clarification of the list of stimuli are necessary.

Keywords

eye tracking, high-tech healthcare, diagnostics, psychiatric disorders, neurological disorders, machine learning, eye movements

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Introduction

The competitiveness of national economies is determined by conditions where the high rate of acquisition of new knowledge and creation of science-intensive products on their own technological basis is a key factor. One of the priorities of scientific and technological development in the next decade should be considered the transition to personalized, predictive and preventive medicine, high-tech healthcare and health-preserving technologies. The response to major challenges should be creation of science-intensive technologies and products that meet the national interests of the Russian Federation and are necessary for a significant improvement in the quality of life of the population.

The transition to "digital healthcare" is likely to be the defining characteristics for the industry. Digital technological innovations, robotics, the Internet of Things, artificial intelligence, and a number of other factors have led to an increase in the use of various digital devices by healthcare professionals, as well as hospital and clinic workers. As a result of digitalization, the industry is also expected to experience institutional shifts: new types of biomedical companies will emerge that will lobby for the transformation of legal norms and rules, the transformation of the institutional landscape regarding the rights, uses, and commercialization of digital technologies in the healthcare system (Doan, Krestyaninova, & Plotnikov, 2023; Zabolotnaya, Gatilova, & Zabolotny, 2020; Bondarenko, & Guzenko, 2021; Rieke et al., 2020; Guo et al., 2020).

Eye tracking as a tool for medical diagnostics

The use of eye tracking in medical practice is another promising area of development that is consistent with current trends in healthcare development and the blurring of disciplinary and industry boundaries in scientific research and development. Firmly entrenched in the field of experimental psychology and originating from the study of the physiology of the visual system, eye tracking is a method of recording a person's gaze, allowing one to calculate indicators of macro- and micro-movements of the eyes. Eye movements reflect a person's thought processes, determining the goal-directed behavior. Recording eye movements allows one to accurately determine which objects attract the observer's gaze, in what order and how often. The development of eye movement recording and processing technology makes it possible to use eye tracking in various fields of activity: neuromarketing, sports, education, psychodiagnostics, etc. This is confirmed by the successful use of eye tracking to study psychological processes and human states, as well as the active patenting of methods for recording oculomotor reactions as part of a comprehensive personality assessment in various fields of activity (Ognev & Likhacheva, 2015). This method improves diagnostics and accelerates the detection of diseases, which ensures faster treatment.

In clinical practice, eye movement monitoring has been conducted for a long time. Precise clinical measurements were carried out as early as the middle of the 20th century. In the works of A. R. Luria, A. Karpov and A. L. Yarbus, two forms of gaze apraxia were first identified, namely occipito-parietal, in which the higher visual functions themselves are primarily affected, and frontal, in which the planning and organization of eye movements is impaired (Karpov, Luria, & Yarbus, 1968; Luria, Karpov & Yarbus, 1966; Karpov, 1975).

The importance of these pioneering works was noted in their review last year by Marim Puchalska et al. (Pąchalska, Buczaj, Kopowski, Pecyna, Maksym, Buczaj, & Rasmus, 2023). It is noted that, although historically eye tracking has been used more in the field of psychology of cognitive processes, eye tracking has the potential to study movement disorders and measure cognitive processes in neurodegeneration. The methods of the mid-20th century made it possible to conduct individual studies, but could not be widely used due to the labor-intensive nature of data recording and processing. Modern technologies are easy to use, reliable, safe, accurate, and can be used in large-scale clinical studies. A detailed description of modern methods of recording eye movements in the field of psychology is given in the review by V. A. Barabanshchikov and A. V. Zhegallo (Barabanshchikov, & Zhegallo, 2014).

Currently, in medical practice, it is possible to conduct large-scale studies of eye movements in a variety of cognitive-emotional disorders. It is possible to detect diseases by monitoring the main types of eye movements, namely fixations, saccades, tremor, and nystagmus. To generate saccades, commands come to the superior colliculus, then to the nuclei of the oculomotor nerves, which directly innervate the eye muscles. Eye movement commands are generated by neural networks of the parietal eye fields

(PEF), the frontal eye field (FEF), the supplementary eye field (SEF), and the dorsolateral prefrontal cortex (DLPFC). Voluntary pro-saccades are mainly under the control of the FEF, while reflexive saccades are generated through PEF neurons. Some saccadic tasks, such as antisaccades, add cognitive layers to the oculomotor pattern and more directly engage the DLPFC and PEF.

Smooth pursuit and fixation of the eyes is initially processed by extrastriatal cortical regions including V5 and the medial superior temporal visual area, connecting to the posterior parietal cortex, FEF, and SEF, and then projecting downward to the pontine nuclei and cerebellum (Russell, Greaves, Convery, Bocchetta, Warren, Kaski, & Rohrer, 2021).

The following tests are used to assess oculomotor activity at the behavioral level:

1. Fixation stability measurement test

Aimed at assessing the ability to maintain gaze on a stationary target, the ability to follow a smoothly moving target, and the ability to maintain fixation stability while reading. Dependent variables: number of blinks, number and amplitude of saccades, average fixation duration, frequency of microsaccades, stability between fixations and within fixations.

2. Saccade assessment tests

This category includes several tests based on saccadic eye movements:

- Prosaccade Test: Measures the ability to quickly and accurately move the eyes to a suddenly appearing target.
- Antisaccade Test: Assesses the ability to suppress a reflexive shift of gaze to a new target and instead move the gaze in the opposite direction.
- Predictive Saccade Test: Assesses the ability to anticipate and move the eyes to where a target will appear based on learned patterns.
- Remembered Saccade Test: Tests the ability to move the eyes to a target location after a delay, requiring remembering the target's location.

Dependent variables: latency, amplitude, direction, peak velocity, accuracy, and corrective saccades.

3. Smooth tracking tests

Includes various methods to assess how well the eyes can follow moving objects:

- Constant Velocity Test: uses a target moving back and forth in a straight line at a constant speed.
- Sinusoidal Test: the target moves in a smooth, wave-like pattern, changing speed.
- Jump-Move Test: the target moves suddenly (a jump) and then continues moving at a constant speed, useful for assessing pursuit onset.
- Dependent Variables: Velocity Ratio, Root Mean Square Error (RMSE), Log Signal-to-Noise Ratio, Number and Type of Saccades (catch-up, retreat, anticipatory saccades), and Pursuit Onset/Acceleration/Velocity.

4. Reading and developing professional skills

Determining the impact of work experience on visual text processing skill: with increasing professional skills in analyzing text information, more optimized eye movement strategies are observed, allowing for efficient task performance with minimal effort (Skuratova et al., 2022). Dependent variables: number of fixations, scan path length, saccade amplitude and velocity.

5. Assessment of medical experience

The qualitative perception of visual images also depends on current professional experience (Figure 1). This is due to learning to recognize low-information low-frequency images presented by the periphery of the visual field to control gaze translation (Skuratova, Shelepin, & Yarovaya, 2021).

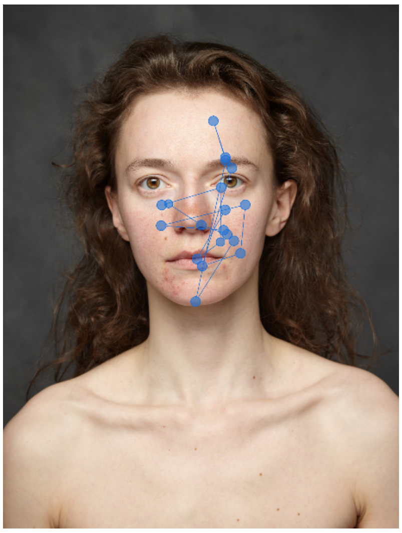
Figure 1

Trajectories of eye movements and fixation points when doctors perceive a patient's face depending on their experience up to one year (a), up to 7 years (b), up to 10 years (c), up to 21 years (d) (Skuratova, Shelepin, & Yarovaya, 2021).

(a) (b)

(c)

(d)



6. Nystagmus

Despite the importance of this clinical indicator, nystagmus is not considered in the current review, as it requires a separate detailed discussion: neurologists qualitatively (visually) assess its condition.

Although eye tracking has obvious potential as a method of medical diagnostics, the use of eye tracking in medical practice and psychodiagnostics currently remains limited: protocols that allow for a comprehensive assessment of a patient's condition have not yet been fully validated.

The purpose of the forthcoming review is an attempt to demonstrate the experience of using eye tracking as an addition to the diagnosis of diseases and disorders, to outline possible trajectories of development of this method in the field of medicine. The article provides examples of the use of eye tracking in various neurological, mental disorders, the review is structured according to the ICD-10 classification.

Results and Discussion

1. Chapter V Mental and behavioral disorders

1.1 Organic, including symptomatic, mental disorders (F00–F09)

The block associated with dementia includes mental disorders with obvious etiologic factors: brain diseases, brain injury or stroke, leading to cerebral dysfunction. Dementia is a syndrome caused by brain damage, in which such higher cortical functions as memory, thinking, orientation, understanding, counting, learning ability, speech and judgment are impaired. This syndrome is observed in Alzheimer's disease, cerebrovascular diseases and other conditions that primarily or secondarily affect the brain (according to: International Classification of Diseases, 10th revision (ICD-10). URL: http://mkb-10.com/index.php?pid=4048).

The category of mild cognitive impairment includes mixed conditions causally related to brain disorders caused by a primary brain disease, a systemic disease secondarily affecting the brain, exposure to exogenous toxic substances or hormones, endocrine disorders or other somatic diseases; dementia is excluded. Alzheimer's disease is a primary degenerative cerebral disease of unknown etiology, manifested by specific neurochemical, neuromorphological, and psychopathological signs (according to: International Classification of Diseases, 10th Revision (ICD-10). URL: http://mkb-10.com/index.php?pid=4048).

Increased microsaccades associated with saccadic intrusions, initially moving the eye away from the visual target and then returning in a corrective manner, are more common in brainstem and cerebellar diseases, and cortical disorders such as Alzheimer's disease (Nakamagoe et al., 2019). Patients with frontotemporal dementia have difficulty maintaining fixation for long periods, which may be explained by a problem with saccade inhibition, especially given the correlation with the orbitofrontal cortex. The smooth pursuit eye movement system is also vulnerable to cerebral dysfunction, with morphological abnormalities found in the visual cortex of patients with idiopathic dementia (Hutton, Nagel, & Loewenson, 1984).

1.1.1 Unspecified dementia (F03)

The following stimuli were used to assess cognitive functions in dementia: scene exploration with social and non-social context, missing elements and social scenes; semantic processing through sentences with matching and mismatching meanings; recognition of image pairs (control: n = 432, dementia: n = 30). Next, a deep learning algorithm was applied to classify and interpret cognitive activity and dementia status based on raw eye tracking parameters (x,y coordinate of gaze, mean pupil size). The obtained results indicate that unsupervised learning methods can complement cognitive assessment for rapid and stress-free monitoring of patients at different stages of the disease, although more research is needed (Mengoudi et al., 2020).

In the study by Russell, Greaves, Convery, Nicholas, Warren, Kaski, & Rohrer (2021), a prosaccade task was initially presented to assess basic oculomotor functions and hence the participant's ability to perform emotion recognition tasks (frontotemporal dementia patients: n = 18, controls: n = 22). Two tasks were designed to assess recognition of simple and complex emotions. Pictures of people with different emotions were shown in the corners of the screen, with the emotion label in the center. Although no statistically significant differences were found on the prosaccade task, the control group spent significantly more time looking at the target image after the label was presented than the dementia group. The controls also spent significantly less time looking at similar and distracting images after the label was presented. The authors note that further research in a larger control group is needed to better understand the reproducibility and reliability of the task (Russell, Greaves, Convery, Nicholas, Warren, Kaski, & Rohrer, 2021).

The study (Córdoba et al., 2023) presents a diagnostic biomarker for Alzheimer's disease (AD) and the behavioral variant of frontotemporal dementia (moderate AD: n = 38, dementia: n = 24, controls: n = 39). Differences were found in saccade, fixation, and smooth pursuit paradigms. Accuracy and area under the curve (AUC) exceed 95%.

1.1.2 Mild cognitive impairment (Mild cognitive disorder F06.7), Alzheimer's disease (G30)

To study these pathological conditions, memory (coding) tasks with tracking a moving coin and separately tracking a falling drop of water (without instructions), deductive reasoning, viewing a landscape photograph, visual working memory (memorization and reproduction), attention and counting, and visuospatial function were proposed. The percentage of fixation duration on each area of interest, x,y coordinates of gaze were taken as dependent variables for the machine learning classifier. The resulting model distinguished cognitive functions in the control group, AD, and mild cognitive impairment subjects, with memory and deductive reasoning tasks being the most indicative (mild cognitive impairment patients: n = 52, Alzheimer's disease patients: n = 70, controls: n = 52). Meanwhile, some tasks can be omitted for further simplification while maintaining good test performance (Tadokoro et al., 2021).

A study (Polden, & Crawford, 2021) examined a visual distraction task. Inhibition of recent distraction (IRD) refers to the suppression of saccadic eye movements toward a target that is located at the location of a previous distractor. Two studies compared IRD in a large cross-cultural sample consisting of young (n=75), older European participants (n = 119), older South Asian participants (n=83), participants with Alzheimer's dementia (n = 65), and participants with mild cognitive impairment (n=91). Significantly longer saccadic reaction times on target-distractor trials compared to target-target trials were evident across all groups, countries, and ages. Importantly, IRD was also preserved in participants with Alzheimer's disease and mild cognitive impairment, demonstrating that IRD is robust across cultures, age groups, and clinical populations.

To investigate visual attention during a test of spatial orientation and navigation ability in Alzheimer's disease, subjects were asked to find a way to a specific location in a VR simulation by navigating the environment with a joystick (n = 15, AD: n = 7, controls: n = 8). Differences in the percentage of fixations on visual cues were found, reflecting the difficulty of AD patients in selecting relevant information for wayfinding compared to controls, paying attention to irrelevant information. The authors note the need for further research, expanding the sample (Davis & Sikorskii, 2020).

1.2 Schizophrenia, schizotypal and delusional disorders (F20–F29)

Schizophrenia is characterized by distortions of thinking, perception, and affect, often in the presence of normal consciousness and intelligence (although cognitive decline may occur over time) (International Classification of Diseases, 10th Revision (ICD-10). URL: http://mkb-10.com/index.php?pid=4048). Patients with schizophrenia often have impaired smooth eye movements during visual target tracking. However, this effect may be the result of pharmacological interventions rather than a reflection of the oculomotor control peculiarities in this disorder. The visual tracking task is relatively difficult, which may be due to dysfunction in areas of the visual motor system (middle temporal area and medial superior temporal area) (Lencer et al., 2005). At the cortical level, self-movement signal processing occurs in the dorsal visual pathway (Bremmer et al., 2000). Disturbances have also been observed in the ventral intraparietal area, which may also contribute to eye movement dysfunction (Ales et al., 2021).

1.2.1 Schizophrenia (F20)

In schizophrenia, eye tracking may be used as a method for detecting malingering in psychiatric practice. Thus, a control group (n = 43) was asked to simulate eye movement patterns demonstrated by a group of patients with schizophrenia (n = 40) in three tasks: smooth pursuit, prosaccade (which served as a baseline measure), and anti-saccade. The dependent variables studied were mean saccade latency, standard deviation of latency, amplitude, peak velocity, number of successful trials, and percentage of errors. Data analysis showed that the eye movements of the participants instructed to simulate (a) were only partially different from the eye movements of the control group and (b) did not closely resemble the eye movements of patients with schizophrenia reported in previously published articles. Together, these results suggest that eye movement testing may indeed help detect malingered schizophrenia (Ales et al., 2021).

In another study, the dependent variables were the number of fixations (NEF), mean scan length (MESL) in the retention task; cognitive search score (CSS), which reflects the frequency of focusing on the regions of interest of the figure for subsequent figure recognition in the comparison task; and responsive search score (RSS), which reflects the frequency of fixations on each part of the figure in response to questions in the comparison task. The RSS of patients with schizophrenia (n = 145) was significantly lower than that of patients with depression (n = 116) or controls (n = 124), while no statistically significant differences were found in RSS between patients with depression and controls. The discriminant function showed a sensitivity of 89.0% and a specificity of 86.7% (Kojima et al., 2001).

The aim of the study (Li et al., 2024) is to compare an ecologically valid measure (Cambridge Prospective Memory Test, CAMPROMPT) and a laboratory-based measure (eye-tracking paradigm) in assessing prospective memory (PM) in individuals with schizophrenia spectrum disorders (SSD). PM performance was assessed using total fixation time and total number of fixations on distractor words. A picture was presented in the center of the screen, four different tokens were presented, and the subjects were asked to determine whether one of the words matched the object in the previously shown picture. Patients with SSD (n = 32) demonstrated fewer total fixations on distractor words and lower PM accuracy compared to controls (n = 32). The laboratory-based eye-tracking paradigm has advantages over ecologically valid measures in detecting signal detection errors, making it a more sensitive tool for identifying PM deficits in patients with SSD.

1.3 Mood [affective] disorders (F30–F39)

In mild, moderate, or severe depressive episodes, patients experience low mood, decreased energy, and decreased activity. The ability to enjoy, joy, be interested, and concentrate is reduced, and there is marked fatigue. The mood disorder block includes disorders in which the main disturbance is a change in emotions and mood toward depression (with or without anxiety) or toward elation (hypomania) (according to: International Classification of Diseases, 10th Revision (ICD-10). URL: http://mkb-10.com/index.php?pid=4048).

The psychopathology of depression is associated with changes in the prefrontal and orbitofrontal cortex. Patients have preserved visual perception, but there are changes in sensorimotor integration processes (Fabisch et al., 2009). Deficits in prosaccades may be related to functional changes affecting cortical structures such as the frontal eye fields (FEF) and the superior colliculus (Schall, 2004). Disruption of deep areas of the FEF may also cause deficits in the visual pursuit system (Rosano et al., 2002). Non-melancholic depressed patients are characterized by an increase in peak saccade velocity. The cerebellum and basal ganglia are brain structures directly involved in the execution of a memory-guided saccade (Dreher & Grafman, 2002). All of these structures interact with other regions such as the dorsolateral prefrontal cortex (DLPFC) (Pierrot-Deseilligny, & Burke, 2005). The DLPFC appears to be involved in the inhibition of saccades generated by the superior colliculus (Kaufman, Pratt, Levine, & Black, 2010). The eye movement inhibition deficits observed in major depression may be related to previously described deficits in (ventrolateral) prefrontal cortex activation and impulsivity in patients with major depression (Carvalho et al, 2015).

1.3.1 Major depressive disorder (F32.2 Severe depressive episode without psychotic symptoms), Bipolar affective disorder (F31)

The study (Wang, Lyu, Tian, Lang, Wang, St Clair, & Zhao, 2022) consisted of the following stages: free viewing task, fixation stability task, and smooth pursuit task (control group: n = 104, patients with major depressive disorder: n = 48, patients with bipolar disorder: n = 57; the corresponding diagnosis was made by psychiatrists based on DSM-IV). In affective disorder, a smaller saccade amplitude was found in the free viewing task, a higher number of fixations and saccades in the fixation stability and smooth pursuit task, shorter fixation duration, longer saccade duration in the fixation stability and smooth pursuit tasks. The authors conclude that patients with major depression, bipolar depression, and bipolar mania have similar eye movement dysfunction in free viewing, fixation stability, and smooth pursuit tasks.

A meta-analysis (patients with depression: n = 474, controls: n = 693) (Huang et al., 2023) showed that:

1. for positive emotional stimuli, the duration of fixation was significantly lower; for negative stimuli, the duration of fixation was higher.
2. the number of fixations on positive emotional stimuli is also lower, the number of fixations on negative emotional stimuli, on the contrary, is higher;
3. age influences the duration of fixation of positive emotional stimuli. In the case of negative emotional stimuli, the duration of fixation was influenced by age and the type of negative emotional picture (sad, dysphoric, threat, anger).

The study (Rantanen et al., 2021) (unipolar depression: n = 16, controls: n = 16) used a free viewing task of visually matching interpersonally aggressive and neutral pictures presented in pairs. When participants were able to anticipate the stimulus valence, depression showed an earlier attentional bias towards interpersonally aggressive pictures. The results demonstrate both an early attentional bias towards interpersonal aggression that may be present in depression and a later attentional bias towards aggression avoidance. The early information processing bias associated with depression may have maladaptive effects on how depressed individuals perceive and function in social interactions and may therefore maintain depressive mood.

The study (Barsznica et al., 2021) describes oculomotor functions in elderly patients with depression and suicidal behavior (SB) based on the prosaccade and antisaccade task. Patients with SB showed a lower number of corrected antisaccade errors and a longer time to correct them than patients without SB. These preliminary results indicate higher cognitive inflexibility in suicidal patients compared to those who are not prone to suicide. Such inflexibility may explain the difficulties of elderly people with depression in finding a solution to the problem of suicidal thoughts in order to adequately respond to a stressful environment.

1.4 Disorders of psychological development (F80–F89) + Behavioural and emotional disorders with onset usually occurring in childhood and adolescence (F90–F98)

A group of childhood disorders with early onset, characterized by disorganized activity, lack of persistence and a tendency to jump from one task to another, social relationships may be impaired, and cognitive functions are insufficient (according to: International Classification of Diseases, 10th revision (ICD-10). URL: http://mkb-10.com/index.php?pid=4048). Childhood autism here is a type of pervasive developmental disorder, which is determined by the presence of: a) abnormalities and delays in development, manifested in a child under three years of age; b) psychopathological changes in all three areas: equivalent social interactions, communication functions and behavior, which is limited, stereotyped and monotonous; c) possible nonspecific problems.

Individuals with ASD demonstrate reduced saccadic eye movement accuracy, the magnitude of which varies across studies. Increased variability suggests deficits in cerebellar variability-reducing functions, resulting in a reduced ability to make compensatory adjustments to ensure consistent and accurate saccade execution. Reduced peak saccade velocity and increased saccade duration may be due to reduced excitatory pontine brainstem burst cell activity and/or increased inhibitory omnipause cell activity, altering saccadic eye movement performance. Reduced ability to consistently modulate saccadic eye movement amplitude may negatively impact early social learning, thereby affecting social and cognitive development (Oldham, Meehan III, & Howell, 2021). On the other hand, in ASD, the mechanisms underlying the ability to direct gaze to a specific stimulus (social or non-social) and hence capture attention are also atypical. They arise from dysfunctions in several brain regions, including the amygdala, frontal eye fields (FEF), temporal parietal junction, insula, and dorsal lateral prefrontal cortex. Attempts are currently being made to elucidate the cortical mechanism of face perception in ASD, however, the eye movement research literature in ASD shows a lack of consistency in the approaches to data collection, analysis, and subsequent interpretation (Papagiannopoulou et al., 2014).

ADHD involves structural/functional abnormalities of the basal ganglia-thalamocortical circuit projecting to the frontal cortex; frontostriatal network. Problems with interpreting abnormal saccades include that saccade performance changes dramatically with age, and involvement of the frontal eye field (FEF) for saccade control has only been demonstrated in lesion studies in adults. Hypofunction of ventral striatum dopaminergic neurons causes motor inhibition failure and may be involved in dysfunction of the limbic region of the prefrontal cortex, i.e., orbitofrontal cortex, anterior cingulate cortex, especially when the ascending output of the basal ganglia is hypofunctioned. These mechanisms may explain the higher distractibility observed in older patients with ADHD (Goto et al., 2010).

1.4.1 Attention deficit disorder (ADHD) (Disturbance of activity and attention F90.0.)

The study by A. Lev et al. (Lev, Braw, Elbaum, Wagner & Rassovsky, 2022) aimed to evaluate the possibility of integrating eye tracking with MOXO-dCPT, a test related to the assessment of cognitive functions in patients with suspected or confirmed ADHD (patients with ADHD: n = 35, controls: n = 35). MOXO-dCPT consists of eight blocks, each block consisting of tasks in which a grid of stimuli (target or non-target) is displayed in the center of the screen. Based on the results of MOXO-dCPT, four performance indices are calculated: attention, timeliness, impulsivity, and hyperactivity. The study also used an 18-item questionnaire for self-report of ADHD symptoms in adults, detailed in DSM-5 (American Psychiatric Association, 2013). The authors considered the duration of gaze to regions of interest: the task stimulus (in the center of the screen), the periphery (the area around the task stimulus), and the area behind the screen. Using gaze direction measurements, it was found that patients with ADHD spent more time looking at irrelevant areas both on and off the screen than control participants. Consistent with the distractibility characteristic of ADHD, difficulty in suppressing spontaneous eye movements toward the MOXO-dCPT distractors appears to be the cause of the group differences. From a clinical perspective, the scale combining eye movement measures and conventional indices has shown the ability to discriminate ADHD, but further studies are needed to confirm the results and address the limitations of the study.

Children with autism spectrum disorder (ASD) have sensory-perceptual processing deficits that impair their ability to pay attention and perceive social stimuli in everyday life. While everyday social episodes consist of subtle dynamic changes in social information, any failure to attend to or process subtle human nonverbal cues such as facial expressions, postures, and gestures can lead to inappropriate social interactions. A study (Tsang & Chu, 2018) collected eye-tracking data while three participants watched a video of a social scenario using a single-case comparison design: a child with autism spectrum disorder (ASD), a child with comorbid attention-deficit hyperactivity disorder (ADHD), and a neurotypical control. The duration of the first fixation (at 500 ms of the target ROI) was longer in the neurotypical child (150 ms) than in children with ASD and ASD-ADHD (both 110 ms). The total fixation duration (per 500 ms target EoI) was shorter for the child with ASD-ADHD (120 ms) than for the neurotypical child (170 ms) and the child with ASD (180 ms). The total number of fixation bursts (per 500 ms target EoI) was highest for the child with ASD (4.62), second highest for the neurotypical child (4.09), and shortest for the child with ASD-ADHD (3.19). The scan path plot captures visual scanning of multiple AOIs in a social scene.

The aim of the study (Sweere et al., 2022) was to examine distractibility, quantified by recording and analyzing task-irrelevant eye movements, in children with and without ADHD and in children with and without neurological disorders (n = 141). Participants with ADHD and participants with neurological disorders spent less time fixating on target stimuli compared to their non-ADHD peers or their peers without neurological disorders. Participants with and without ADHD had similar press latencies. Participants with neurological disorders had longer press latencies compared to their typically developing peers. Target fixation duration showed a significant association with parent-reported attention problems. The authors conclude that eye tracking during a distraction task provides potentially valid clinical information that can facilitate the assessment of dysfunctional attention processes. Further research into the validity and reliability of this paradigm is recommended.

The aim of the work (Oliveira, Franco, Revers, Silva, Portolese, Brentani, & Nunes, 2021) was to study the Visual attention model (VAM) for the diagnosis of ASD and ADHD (ADHD patients: n = 30, ASD patients: n = 76). Three videos with human movements and three videos with geometric shapes were combined into nine videos displayed sequentially, with a total duration of 54 s. The order and position of frames with human and shape movements varied throughout the video. A fixation map was used to train the model. The result was a model for the diagnosis of ASD and ADHD based on the use of video as a stimulus with an average accuracy of 90%, recall of 69%, and specificity of 93%.

A study (Kong et al., 2022) analyzed the gaze patterns of 1.5–3-year-old children (n = 95) and 3–5-year-old children (n = 74) with and without ASD while viewing video clips and still images. The percentage of fixation time in children with ASD was significantly reduced compared to that in normal children in almost all ROIs, except for a moving toy (helicopter). Support vector machine analysis showed that the classifier could differentiate ASD from normal in toddlers with 80% accuracy and differentiate ASD from normal in preschoolers with 71% accuracy.

The study (Vacas et al., 2021) aimed to compare visual attention patterns to social and non-social images in children with ASD and matched controls (n=36), assessing the role of emotion in the face stimuli and the type of competing object. A paired preference task was designed pairing happy, angry, and neutral faces with two types of objects (related or unrelated to their autism-related CIs). Three indices were considered as dependent variables: prioritization (attentional orientation), preference, and duration (sustained attention). Results showed that both groups had similar visual patterns to faces (prioritization, greater attention, and longer attendance to faces paired with objects unrelated to their CIs); however, the ASD group attended to faces significantly less than the controls. Children with ASD showed an emotional bias (late orienting to angry faces and typical preference for happy faces). Finally, objects related to their concomitant restricted interests attracted attention in both groups, which significantly reduced social attention in children with ASD. Atypical social attention is present in children with ASD regardless of the competing nonsocial object.

2. Chapter IX Diseases of the circulatory system

Stroke is an acute disturbance of blood circulation in the brain, accompanied by tissue death and dysfunction of the nervous system. The consequences of stroke include conditions specified as such, as residual effects, or as conditions that exist for a year or more from the onset of the causative condition (according to: International Classification of Diseases, 10th revision (ICD-10). URL: http://mkb-10.com/index.php?pid=4048).

Pupillary dilation is controlled by both the sympathetic and parasympathetic nervous systems in response not only to changes in light but also to cognitive processes including attention, memory, language, decision making, and emotional processing. Receiving, processing, and recognizing emotional information from the human face involves a complex network of peripheral and central systems. In addition to the visual cortex and cortical association areas that are typically involved in visual processing, other brain regions such as the fusiform face area in the ventral temporal lobes are also involved in the decoding of emotional information when imaging the human face. Other structures such as the inferior occipital gyrus, superior temporal sulcus, and amygdala are also involved in decoding emotional information. The distributed nature of these brain circuits makes them particularly vulnerable to both focal and diffuse damage, such as that resulting from cerebrovascular and traumatic events, as evidenced by the high incidence of impairments in emotion discrimination following brain injury (Maza, Moliner, Ferri & Llorens, 2020).

The absence of pathological rightward bias during free scene viewing may depend on the integrity of the second branch of the right superior longitudinal fasciculus (SLF II), a white matter tract connecting cortical areas critical for visual attention, and damage to which is closely associated with the occurrence of neglect (Kaufmann et al., 2020).

2.1 Stroke (Sequelae of cerebrovascular disease I69)

Spatial neglect is associated with the inability to observe and respond to the contralateral hemispace and is a negative predictor of functional outcomes after stroke (Ales et al., 2021). The aim of the study was to test the sensitivity of eye movement measurement during Free Visual Exploration (FVE) (stroke patients: n = 78, controls: n = 40). Twelve images of nature or urban public spaces and 12 mirrored versions (reflected along the vertical axis) were presented on the screen. The instruction was to freely explore the images. The direction of first fixation (left or right) and average gaze duration were examined. Patients with neglect demonstrated a rightward bias in free visual exploration. FVE correctly detected neglect in 85% of patients with an AUC value of 0.922 in the ROC analysis. Traditional paper-based neuropsychological tests, considered alone or in combination, showed heterogeneous results and were significantly less likely to detect neglect (21.74%–68.75%). Eye tracking was more sensitive in detecting neglect in everyday behavior than neuropsychological tests (Kaufmann et al., 2020).

The study (Maza, Moliner, Ferri & Llorens, 2020) examined accuracy, response distribution, visual behavior and pupil dilation in stroke survivors when recognizing emotional facial expressions (ischemic stroke: n = 18, hemorrhagic stroke: n = 22, controls: n = 65). The authors' results confirmed the deterioration of performance after stroke and showed a decrease in attention to the eyes. The dependence of visual behavior on performance, although not determinative, may indicate that altered visual behavior may be a factor negatively affecting the recognition of emotions from facial expressions.

Gaze-evoked nystagmus (GEN) is a central feature of acute vestibular syndrome (AVS); however, distinguishing pathological from physiological GEN is challenging. In controls with GEN, the centripetal drift time constant was >18 s. Eye tracking detected pathological GEN (time constant ≤ 18 s) in 33% of patients with vestibular strokes. The results were equivalent to specialist examination. Automated GEN quantification was specific and accurately identified patients in the emergency department with stroke-induced AVS (Mantokoudis, Korda, Zee, Zamaro, Sauter, Wagner, & Caversaccio, 2021).

3. Chapter VI Diseases of the nervous system

Multiple sclerosis is an autoimmune disease caused by a malfunction of the body's immune system. Parkinson's disease includes movement disorders resulting from the death of neurons in the substantia nigra of the brain.

In multiple sclerosis, inflammatory demyelinating lesions in different brain regions result in a wide range of oculomotor abnormalities, most commonly static and dynamic eye movements (Serra, Chisari & Matta, 2018) combined with dysmetric saccadic behavior (Serra, Derwenskus, Downey & Leigh, 2003). Fixation (Mallery et al., 2018), smooth pursuit (Lizak et al., 2016), and vestibulo-ocular responses (Huygen et al., 1990) are also frequently impaired. Most of these abnormalities are exacerbated by the presence of internuclear ophthalmoplegia (INO). INO is a neuro-ophthalmic disorder occurring in approximately one in three patients with multiple sclerosis (Jozefowicz-Korczynska, Łukomski & Pajor, 2008) and characterized by impaired adduction of conjugate lateral eye movements. The presence of INO is often decisive for confirming the diagnosis of multiple sclerosis, especially if it is bilateral (Bolanos, Lozano & Cantu, 2004), but its subclinical manifestations are difficult to detect without quantitative approaches (Matsumoto et al., 2011).

The frontal, supplementary and parietal eye fields, prefrontal and posterior parietal cortex project to brainstem structures that control saccades via the superior colliculus, thalamus and basal ganglia. Within this brainstem-parietotemporal and basal ganglia-frontal neutral network, there is a two-way interaction between voluntary eye movements and attentional switches, with the former exerting bottom-up control over the latter and the latter exerting top-down influence on the former. In addition, fixation saccades and microsaccades play an important role in information selection during free visual scanning and search, with the speed increasing depending on the size of the scanned scene and the level of information content. Abnormal visual scanning is not uncommon in Parkinson's disease, and the deficit increases with the complexity of visual images (Matsumoto et al., 2011). Saccade abnormalities caused by cortical and subcortical neurodegenerative changes are also observed in PD (Rascol et al., 1989). Increased saccade latency, impaired saccade programming and execution, error rates, and reduced saccade amplitude are typical in patients with idiopathic non-demented Parkinson's disease (Beylergil et al., 2022).

3.1 Demyelinating diseases of the central nervous system (G35–G37) + Extrapyramidal and movement disorders (G20–G26)

3.1.1 Multiple sclerosis (G35) and Parkinson's disease (G20)

The SONDA (Standardized Oculomotor and Neurological Disorder Assessment) test is based on the analysis of eye tracking recorded during a short and intuitive continuous tracking task. The visual stimulus is represented by a Gaussian spot of increased luminance moving along a random walk trajectory on a uniform gray background (~140 cd/m2). There were two stimulus presentation conditions: in the smooth tracking condition, the stimulus moved continuously along the random walk path, and in the saccadic tracking condition, an additional positional shift to a random location on the screen was added to the trajectory, which occurred every 2 s. Using the SONDA approach presented in the study by Grillini et al. (2020) found preserved smooth pursuit responses and two abnormal features in the saccadic pursuit condition in MS, but this finding is limited by the sample size (PD patients: n = 9, MS patients: n = 12, controls: n = 50). Slower saccades are to be expected in advanced PD. One of the characteristic oculomotor abnormalities in PD is the impairment of self-generated saccades with relative preservation of visually guided saccades, which worsens as the disease progresses. Most errors are made when

PD patients have to switch between instructions (e.g., switching between pro- and antisaccades) (Grillini, Renken, Vrijling, Heutink, & Cornelissen, 2020).

In a study (Brien, Riek, Yep, Huang, Coe, & Areshenkoff, 2023), patients with Parkinson's disease (n = 121: 45 cognitively intact/45 MCI/20 dementia/11 others) and controls (n = 106) were given a pro/antisaccade task. Using saccade, pupil, and blink parameters, the classifier achieved 83% sensitivity and 78% specificity. Confidence scores predicted motor and cognitive performance in PD. The resulting model can be used as an additional screening tool in the clinic.

Eye movements and horizontal and vertical angular position vectors of the right and left eyes were also measured using high-resolution video-oculography in a cohort of patients with Parkinson's disease who viewed a blank scene and images of a real scene. The latter was associated with the task of finding an object among other objects in an expected and unexpected location. The group of people with Parkinson's disease took longer to find the object. The final response time was comparable in both patients with Parkinson's disease and controls (patients with Parkinson's disease: n = 13, controls: n = 7). Fixation duration was comparable in the two groups, but tended to be shorter for stimuli located in atypical locations. Participants with Parkinson's disease made more fixational saccades with significantly larger amplitude and fewer non-fixational saccades with significantly smaller amplitude while viewing the blank scene. However, the total scan area of the blank scene was not affected by Parkinson's disease. Participants with Parkinson's disease made fewer non-fixational saccades during visual search for a target object, with amplitudes comparable to healthy controls. Fixational saccades during visual search were greater in Parkinson's disease, especially when the target was placed in an unexpected location, but the frequency did not change (Beylergil, Kilbane, Shaikh, & Ghasia, 2022).

4. Chapter XIX Injury, poisoning and certain other consequences of external causes

4.1 Injuries to the head

Concussion is the result of a biomechanical impact to the head that disrupts normal brain function (McCrory et al., 2009). The integrity of multiple brain regions (occipital lobe, parietal lobe, frontal eye field, brainstem, and connecting pathways) is necessary for the preservation of vision and vestibulo-ocular reflexes (Ciuffreda et al., 2007). Because concussion is likely a diffusely distributed injury, visual impairment may be common (Zahid et al., 2020).

4.1.1. Concussion (S06.0)

The aim of the study (Oldham, Meehan III, & Howell, 2021) was to (1) examine the association between patient-reported symptoms and concussion-related eye tracking impairments and (2) compare gait quality between (a) adolescents with concussion who have normal eye tracking, (b) adolescents with concussion who have impaired eye tracking, and (c) controls (concussion: n = 30, controls: n = 30). BOX (pupil dehiscence index) assessment was performed, the Post-Concussion Symptom Scale (PCSS) was administered, and gait speed was measured with triaxial inertial measurement units. The concussion and eye tracking impairment group had higher overall symptom severity and worse symptom severity across the 5 PCSS symptom profiles. In the eye-tracking study, participants watched a short video that moved across a screen. The concussion group with abnormal eye tracking had worse overall symptom severity and higher scores on each of the 5 symptom profiles than the normal eye-tracking and healthy control groups. Additionally, the abnormal eye-tracking group walked at a slower speed when performing one and two tasks, although the difference was not statistically significant. The authors conclude that eye tracking is a clinically useful tool for identifying visual and motor impairment after concussion, and suggest that further research is needed to determine whether eye tracking can help clinicians monitor people at risk for prolonged recovery from concussion.

The authors (Zahid et al., 2020) evaluated an automated eye tracking algorithm as a biomarker of concussion, defined by its symptoms and clinical signs of convergence insufficiency and accommodative dysfunction, in a pediatric population (children with concussion: n = 56, controls: n = 83). Metrics comparing the speed and coupling of eye movements over time were derived and compared with the correlation between acute concussion assessment (ACE) scores, convergence, and accommodative dysfunction. Twelve eye tracking metrics differed significantly between children with and without concussion. The model for classifying concussion as diagnosable by its symptoms assessed using ACE achieved an area under the curve (AUC) = 0.854 (sensitivity 71.9%, specificity 84.4%, cross-validated AUC = 0.789). An eye tracking model designed to detect near point of convergence (NPC) disability achieved a specificity of 95.8% and a sensitivity of 57.1% with an AUC of 0.810. Eye tracking correlated with concussion symptoms and identified convergence and accommodation impairments associated with concussion in a pediatric population. It demonstrated utility as a rapid, objective, and noninvasive method for diagnosing concussion.

Conclusion

Eye movements are probably the best way to assess the state of the brain mechanisms that determine the purposeful activity of a person. Based on the measurement of eye movement characteristics, the effectiveness of this activity can be measured. The analysis showed that the advantages of eye tracking over other methods include: objectivity, expressed in independence from the interpretation of a complex cognitive state by a diagnostician, brief and stress-free observation of patients, the ability to simplify the tasks presented with high diagnostic accuracy, finding a simulated disorder, supplementing existing tests, searching for latent features (especially characteristic of machine learning-based models), higher sensitivity compared to some neuropsychological tests, the ability to dynamically switch between tasks. The general features of the design of research in the field of medical diagnostics include:

- Using existing paradigms for conducting eye tracking studies;
- Combining new paradigms with existing neuropsychological tests and methods;
- Inheriting the basic principles of examining a patient's condition;
- Building data analysis models;
- Building models of purposeful human behavior.

Eye tracking as a possible method of medical diagnostics has a high potential for complementing and refining other research methods. As a further direction for the development of this method, it is necessary to validate the protocols on an extended sample, assess the sufficiency of the stimulus material for the expected oculomotor reaction, and consider the possibility of combining with already accepted diagnostic methods to obtain additional information.

References

Barabanshchikov, V. A., Zhegallo, A. V. (2014). Methods of recording eye movements in psychology: basics of the educational and methodological complex. *Experimental Psychology*, 7(1), 132–137. (In Russ.)

Bondarenko, V. A., Guzenko, N. V. (2021). Digitalization of the Russian healthcare sector: "smart technologies" in ensuring quality of life. *Bulletin of the South-Russian State Technical University (NPI) Series Socio-Economic Sciences*, 14(1), 103–113. (In Russ.)

Doan, T. M., Krestyaninova, O. G., Plotnikov, V. A. (2023). Digitalization of Healthcare: Promising Tools. *Economics and Management*, 29(2), 132–140. (In Russ.)

Zabolotnaya, N. V., Gatilova, I. N., Zabolotny, A. T. (2020). Digitalization of Healthcare: Achievements and Development Prospects. *Economics. Informatics*, 47(2), 380–389. (In Russ.)

Karpov, V. A. (1975). *On some results of the study of the features of gaze control in syndromes of damage to the frontal systems of the brain*. B. F. Lomov, N. Yu. Vergiles (eds.) In: *Motor components of vision*. Science M. (In Russ.)

Ognev, A. S., Likhacheva, E. V. (2015). Validity of eye tracking as a tool for psychodiagnostics. *Advances in modern natural science*, 1-8, 1311–1314.

Skuratova, K. A., Shelepin, E. Yu., Yarovaya, N. P. (2021). Optical search and visual skill. *Optical journal*, 88(12), 28. (In Russ.)

Ales, F., Giromini, L., Warmelink, L., Polden, M., Wilcockson, T., Kelly, C. & Crawford, T. (2021). An eye tracking study on feigned schizophrenia. *Psychological Injury and Law, 14*(3), 213–226.

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.).

Barsznica, Y., Noiret, N., Lambert, B., Monnin, J., De Pinho, C., Hickel, J. & Chopard, G. (2021). Saccadic eye movements in elderly depressed patients with suicidal behaviors: an exploratory eye-tracking study. *Frontiers in psychology*, 12, 712347.

Beylergil, S. B., Kilbane, C., Shaikh, A. G., & Ghasia, F. F. (2022). Eye movements in Parkinson's disease during visual search. *Journal of the Neurological Sciences*, 440, 120299.

Bolanos, I., Lozano, D., & Cantu, C. (2004). Internuclear ophthalmoplegia: causes and long-term follow-up in 65 patients. *Acta Neurologica Scandinavica, 110*(3), 161–165.

Bremmer, F., Duhamel, J. R., Hamed, S. B., & Graf, W. (2000). Stages of self-motion processing in primate posterior parietal cortex. *International Review of Neurobiology*, 44, 173–198.

Brien, D. C., Riek, H. C., Yep, R., Huang, J., Coe, B., Areshenkoff, C. & ONDRI Investigators. (2023). Classification and staging of Parkinson's disease using video-based eye tracking. *Parkinsonism & Related Disorders*, 110, 105316.

Carvalho, N., Laurent, E., Noiret, N., Chopard, G., Haffen, E., Bennabi, D., & Vandel, P. (2015). Eye movement in unipolar and bipolar depression: A systematic review of the literature. *Frontiers in psychology*, 6, 1809.

Ciuffreda, K. J., Kapoor, N., Rutner, D., Suchoff, I. B., Han, M. E., & Craig, S. (2007). Occurrence of oculomotor dysfunctions in acquired brain injury: a retrospective analysis. *Optometry-Journal of the American Optometric Association, 78*(4), 155–161.

Córdoba, A. C., Cena, C. E. G., Lage, C., & Juan, P. S. (2023). *Eye Tracking and Machine Learning Non-invasive Biomarker for Alzheimer's Disease and Frontotemporal Dementia Diagnosis.* In: Proceedings of the Latin American Congress on Automation and Robotics (pp. 113–122). Cham: Springer Nature Switzerland.

Davis, R., & Sikorskii, A. (2020). Eye tracking analysis of visual cues during wayfinding in early stage Alzheimer's disease. *Dementia and geriatric cognitive disorders, 49*(1), 91–97.

Dreher, J. C., & Grafman, J. (2002). The roles of the cerebellum and basal ganglia in timing and error prediction. *European Journal of Neuroscience, 16*(8), 1609–1619.

Fabisch, K., Fitz, W., Fabisch, H., Haas-Krammer, A., Klug, G., Zapotoczky, S., & Kapfhammer, H. P. (2009). Sinusoidal smooth pursuit eye tracking at different stimulus frequencies: position error and velocity error before catch-up saccades in schizophrenia and in major depressive disorder. *Australian & New Zealand Journal of Psychiatry, 43*(9), 855–865.

Goto, Y., Hatakeyama, K., Kitama, T., Sato, Y., Kanemura, H., Aoyagi, K. & Aihara, M. (2010). Saccade eye movements as a quantitative measure of frontostriatal network in children with ADHD. *Brain and Development, 32*(5), 347–355.

Grillini, A., Renken, R. J., Vrijling, A. C., Heutink, J., & Cornelissen, F. W. (2020). Eye movement evaluation in multiple sclerosis and Parkinson's disease using a standardized oculomotor and neuro-ophthalmic disorder assessment (SONDA). *Frontiers in Neurology*, 11, 971.

Guo, C., Ashrafian, H., Ghafur, S., Fontana, G., Gardner, C., & Prime, M. (2020). Challenges for the evaluation of digital health solutions–A call for innovative evidence generation approaches. *NPJ Digital Medicine, 3*(1), 110.

Heilman, K. M., Watson, R. T., Valenstein E. (1993). *Neglect and related disorders*. New York Oxford University Press.

Huang, G., Li, Y., Zhu, H., Feng, H., Shen, X., & Chen, Z. (2023). Emotional stimulation processing characteristics in depression: Meta-analysis of eye tracking findings. *Frontiers in Psychology*, 13, 1089654.

Hutton, J. T., Nagel, J. A., & Loewenson, R. B. (1984). Eye tracking dysfunction in Alzheimer-type dementia. *Neurology, 34*(1), 99–99.

Huygen, P. L. M., Verhagen, W. I. M., Hommes, O. R., & Nicolasen, M. G. M. (1990). Short vestibule-ocular reflex time constants associated with oculomotor pathology in multiple sclerosis. *Acta oto-laryngologica, 109*(1–2), 25–33.

Jozefowicz-Korczynska, M., Łukomski, M., & Pajor, A. (2008). Identification of internuclear ophthalmoplegia signs in multiple sclerosis patients: saccade test analysis. *Journal of neurology*, 255, 1006–1011.

Karpov, A. R. Luria, A. L., & Yarbus, A. L. (1968) Disturbances of the structure of active perception in lesions of the posterior and anterior regions of the brain. *Neuropsychologia, 6*(2), 157–166.

Kaufmann, B. C., Cazzoli, D., Pflugshaupt, T., Bohlhalter, S., Vanbellingen, T., Müri, R. M. & Nyffeler, T. (2020). Eyetracking during free visual exploration detects neglect more reliably than paper-pencil tests. *Cortex*, 129, 223–235.

Kaufman, L. D., Pratt, J., Levine, B., & Black, S. E. (2010). Antisaccades: a probe into the dorsolateral prefrontal cortex in Alzheimer's disease. A critical review. *Journal of Alzheimer's Disease, 19*(3), 781–793.

Kojima, T., Matsushima, E., Ohta, K., Toru, M., Han, Y. H., Shen, Y. C. & Prilipko, L. (2001). Stability of exploratory eye movements as a marker of schizophrenia–a WHO multi-center study. *Schizophrenia Research, 52*(3), 203–213.

Kong, X. J., Wei, Z., Sun, B., Tu, Y., Huang, Y., Cheng, M., & Wan, G. (2022). Different eye tracking patterns in autism spectrum disorder in toddler and preschool children. *Frontiers in Psychiatry*, 13, 899521.

Lencer, R., Nagel, M., Sprenger, A., Heide, W., & Binkofski, F. (2005). Reduced neuronal activity in the V5 complex underlies smooth-pursuit deficit in schizophrenia: evidence from an fMRI study. *Neuroimage, 24*(4), 1256–1259.

Lev, A., Braw, Y., Elbaum, T., Wagner, M., & Rassovsky, Y. (2022). Eye tracking during a continuous performance test: Utility for assessing ADHD patients. *Journal of Attention Disorders, 26*(2), 245–255.

Li, H., Wang, Q., Hou, W. P., Chen, D. Y., Ding, Y. S., Zhang, Z. F. & Wang, C. Y. (2024). Further clarification of cognitive processes of prospective memory in schizophrenia by comparing eye-tracking and ecologically-valid measurements. *Schizophrenia, 10*(1), 41.

Lizak, N., Clough, M., Millist, L., Kalincik, T., White, O. B., & Fielding, J. (2016). Impairment of smooth pursuit as a marker of early multiple sclerosis. *Frontiers in Neurology*, 7, 228947.

Luria, A. R., Karpov, B. A., & Yarbus, A. L. (1966). Disturbaces of active visual perception with lesions of frontal lobes. *Cortex, 2*(2), 202–212.

Mallery, R. M., Poolman, P., Thurtell, M. J., Full, J. M., Ledolter, J., Kimbrough, D. & Kardon, R. H. (2018). Visual fixation instability in multiple sclerosis measured using SLO-OCT. *Investigative Ophthalmology & Visual Science, 59*(1), 196–201.

Mantokoudis, G., Korda, A., Zee, D. S., Zamaro, E., Sauter, T. C., Wagner, F., & Caversaccio, M. D. (2021). Bruns' nystagmus revisited: a sign of stroke in patients with the acute vestibular syndrome. *European Journal of Neurology, 28*(9), 2971–2979.

Martínez, A., Hillyard, S. A., Dias, E. C., Hagler, D. J., Butler, P. D., Guilfoyle, D. N. & Javitt, D. C. (2008). Magnocellular pathway impairment in schizophrenia: evidence from functional magnetic resonance imaging. *Journal of Neuroscience, 28*(30), 7492–7500.

Matsumoto, H., Terao, Y., Furubayashi, T., Yugeta, A., Fukuda, H., Emoto, M. & Ugawa, Y. (2011). Small saccades restrict visual scanning area in Parkinson's disease. *Movement Disorders, 26*(9), 1619–1626.

Maza, A., Moliner, B., Ferri, J., & Llorens, R. (2020). Visual behavior, pupil dilation, and ability to identify emotions from facial expressions after stroke. *Frontiers in Neurology*, 10, 484567.

Mengoudi, K., Ravi, D., Yong, K. X., Primativo, S., Pavisic, I. M., Brotherhood, E., Alexander, D. C. (2020). Augmenting dementia cognitive assessment with instruction-less eye-tracking tests. *IEEE Journal of Biomedical and Health Informatics*, *24*(11), 3066–3075.

McCrory, P., Meeuwisse, W., Johnston, K., Dvorak, J., Aubry, M., Molloy, M., & Cantu, R. (2009). Consensus statement on Concussion in Sport. *South African Journal of Sports Medicine, 21*(2).

Nakamagoe, K., Yamada, S., Kawakami, R., Koganezawa, T., & Tamaoka, A. (2019). Abnormal saccadic intrusions with Alzheimer's disease in darkness. *Current Alzheimer Research*, *16*(4), 293–301.

Oldham, J. R., Meehan III, W. P., & Howell, D. R. (2021). Impaired eye tracking is associated with symptom severity but not dynamic postural control in adolescents following concussion. *Journal of Sport and Health Science, 10*(2), 138–144.

Oliveira, J. S., Franco, F. O., Revers, M. C., Silva, A. F., Portolese, J., Brentani, H., & Nunes, F. L. (2021). Computer-aided autism diagnosis based on visual attention models using eye tracking. *Scientific Reports, 11*(1), 10131.

Papagiannopoulou, E. A., Chitty, K. M., Hermens, D. F., Hickie, I. B., & Lagopoulos, J. (2014). A systematic review and meta-analysis of eye-tracking studies in children with autism spectrum disorders. *Social Neuroscience, 9*(6), 610–632.

Pierrot-Deseilligny, E., & Burke, D. (2005). *The circuitry of the human spinal cord: its role in motor control and movement disorders*. Cambridge university press.

Polden, M., & Crawford, T. J. (2021). Active visual inhibition is preserved in the presence of a distracter: A cross-cultural, ageing and dementia study. *Cortex*, 142, 169–185.

Rantanen, M., Hautala, J., Loberg, O., Nuorva, J., Hietanen, J. K., Nummenmaa, L., & Astikainen, P. (2021). Attentional bias towards interpersonal aggression in depression–An eye movement study. *Scandinavian Journal of Psychology, 62*(5), 639–647.

Rascol, O., Clanet, M., Montastruc, J. L., Simonetta, M., Soulier-Esteve, M. J., Doyon, B., & Rascol, A. (1989). Abnormal ocular movements in Parkinson's disease: evidence for involvement of dopaminergic systems. *Brain, 112*(5), 1193–1214.

Rieke, N., Hancox, J., Li, W., Milletari, F., Roth, H. R., Albarqouni, S., & Cardoso, M. J. (2020). The future of digital health with federated learning. *NPJ Digital Medicine, 3*(1), 1–7.

Rosano, C., Krisky, C. M., Welling, J. S., Eddy, W. F., Luna, B., Thulborn, K. R., & Sweeney, J. A. (2002). Pursuit and saccadic eye movement subregions in human frontal eye field: a high-resolution fMRI investigation. *Cerebral Cortex, 12*(2), 107–15.

Russell, L. L., Greaves, C. V., Convery, R. S., Bocchetta, M., Warren, J. D., Kaski, D., & Rohrer, J. D. (2021). Eye movements in frontotemporal dementia: Abnormalities of fixation, saccades and anti-saccades. *Alzheimer's & Dementia: Translational Research & Clinical Interventions, 7*(1), e12218.

Russell, L. L., Greaves, C. V., Convery, R. S., Nicholas, J., Warren, J. D., Kaski, D., & Rohrer, J. D. (2021). Novel instructionless eye tracking tasks identify emotion recognition deficits in frontotemporal dementia. *Alzheimer's Research & Therapy*, 13, 1–11.

Schall, J. D. (2004). On the role of frontal eye field in guiding attention and saccades. *Vision Research, 44*(12), 1453–1467.

Serra, A., Chisari, C. G., & Matta, M. (2018). Eye movement abnormalities in multiple sclerosis: pathogenesis, modeling, and treatment. *Frontiers in Neurology*, 9, 313229.

Serra, A., Derwenskus, J., Downey, D. L., & Leigh, R. J. (2003). Role of eye movement examination and subjective visual vertical in clinical evaluation of multiple sclerosis. *Journal of Neurology*, 250, 569–575.

Skuratova, K. A., Shelepin, E. Y., Malashin, R. O., & Shelepin, Y. E. (2022). Image analysis and error detection in source software code. *Journal of Optical Technology, 89*(8), 476–483.

Sweere, D. J., Pel, J. J., Kooiker, M. J., van Dijk, J. P., van Gemert, E. J., Hurks, P. P. & Hendriksen, J. G. (2022). Clinical utility of eye tracking in assessing distractibility in children with neurological disorders or ADHD: A cross-sectional study. *Brain Sciences, 12*(10), 1369.

Tadokoro, K., Yamashita, T., Fukui, Y., Nomura, E., Ohta, Y., Ueno, S., & Abe, K. (2021). Early detection of cognitive decline in mild cognitive impairment and Alzheimer's disease with a novel eye tracking test. *Journal of The Neurological Sciences*, 427, 117529.

Tsang, V., & Chu, P. C. K. (2018). Comparing eye-tracking data of children with high-functioning ASD, comorbid ADHD, and of a control watching social videos. *JoVE (Journal of Visualized Experiments)*, (142), e58694.

Vacas, J., Antolí, A., Sánchez-Raya, A., Pérez-Dueñas, C., & Cuadrado, F. (2021). Visual preference for social vs. non-social images in young children with autism spectrum disorders. An eye tracking study. *Plos One, 16*(6), e0252795.

Wang, Y., Lyu, H. L., Tian, X. H., Lang, B., Wang, X. Y., St Clair, D. & Zhao, J. (2022). The similar eye movement dysfunction between major depressive disorder, bipolar depression and bipolar mania. *The World Journal of Biological Psychiatry, 23*(9), 689–702.

Zahid, A. B., Hubbard, M. E., Lockyer, J., Podolak, O., Dammavalam, V. M., Grady, M. & Master, C. L. (2020). Eye tracking as a biomarker for concussion in children. *Clinical Journal of Sport Medicine, 30*(5), 433–443.

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Author Contributions

Evgeny Yu. Shelepin – work with literary sources, writing and analysis of the text of the article;

Ksenia A. Skuratova – analysis of scientific literature, writing of the text of the article;

Polina A. Lekhnitskaya – analysis of scientific literature, writing of the text of the article;

Konstantin Yu. Shelepin – analysis of scientific literature, writing of the text of the article.

Author Details

Evgeny Yu. Shelepin – Researcher, Laboratory of Speech Psychophysiology, Pavlov Institute of Physiology, Russian Academy of Sciences, St. Petersburg, Russian Federation; Scopus Author ID: 57224279100; SPIN-code RINTS: 5938-7368; ORCID ID: https://orcid.org/0000-0002-3124-5540; e-mail: ShelepinEY@infran.ru

Ksenia A. Skuratova – Junior Researcher, Laboratory of Vision Physiology, Pavlov Institute of Physiology, Russian Academy of Sciences, St. Petersburg, Russian Federation; Scopus Author ID: 57216979736; SPIN-code RINTS: 5940-0930; ORCID ID: https://orcid.org/0000-0001-8371-4348; e-mail: kseskuratova@gmail.com

Polina A. Lekhnitskaya – student, Federal State Autonomous Educational Institution of Higher Education Kazan (Volga Region) Federal University, Kazan, Russian Federation; Scopus Author ID: 58683671900; SPIN-code RINTS: 2796-3501; ORCID ID: https://orcid.org/0000-0002-3689-3213; e-mail: lekhnitskaya.polina@gmail.com

Konstantin Yu. Shelepin – Cand.Sci.(Medical Sciences), research associate, Laboratory of Speech Psychophysiology, Pavlov Institute of Physiology, Russian Academy of Sciences, St. Petersburg, Russian Federation; Scopus Author ID: 57148212900; RSCI SPIN code: 4250-4127; ORCID ID: https://orcid.org/0000-0003-2218-9716; e-mail: shelepink@yandex.ru

Conflict of Interest Information

The authors have no conflicts of interest to declare.