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FEATURES OF OCULOMOTOR REACTIONS IN HIGHLY ANXIOUS VOLUNTEERS WITH DIFFERENT LEVEL OF IMPULSITY IN SOLVING DIFFERENT TYPES OF THE ANTI-SACCADE TASK

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Introduction. Impulsivity, manifested in the difficulty of suppressing certain actions, is often associated with increased anxiety. Depending on the level of impulsivity, individuals with higher anxiety react differently to tasks requiring inhibitory control. The anti-saccade task is one of the psychophysiological approaches to assessing visual attention and inhibitory control. This study aimed to test a hypothesis that individuals with high levels of impulsivity and anxiety would have different eye movement patterns in the anti-saccade task compared to highly anxious individuals with low levels of impulsivity. **Methods.** Twenty volunteers with low impulsivity and fourteen volunteers with higher impulsivity performed 3 blocks of anti-saccade tasks, differing in the effect of Step, Gap, and Overlap with fixation and target stimuli of negative, positive, and neutral emotional valence. All participants had increased trait and state anxiety. The eye-movement patterns were recorded using an eye-tracking method. **Results.** Significant differences were observed between groups in the regular error mean latency in the Overlap block and the regular error mean amplitude in the Gap block. The Overlap effect caused longer latencies of erroneous saccades while the Gap effect produced lower amplitudes of erroneous saccades in the group with increased trait impulsivity in the tasks where neutral stimuli were used either as fixation or target stimuli. **Conclusion.** Our findings imply that different designs of the anti-saccade task are able to reveal specific patterns of eye movements associated with attention switching and inhibitory control in impulsive behavior.

Keywords: anti-saccade task, eye tracking, impulsivity, anxiety, inhibitory control

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1. INTRODUCTION

High level of impulsivity and anxiety are a key premorbid feature of psychiatric disorders such as attention deficit and hyperactivity disorder (ADHD), substance abuse, gambling, obsessive-compulsive disorder and other personality disorders (Nigg, 2013; Summerfeldt et al., 2004). These properties influence not only the development of psychopathology but also affects learning, health risks (smoking, obesity, accidents), and general well-being (Masaki et al., 2022; Moffitt et al., 2011; Nigg, 2006; Rebetez et al., 2018).

Impulsivity and anxiety may have both general and specific traits as in neuronal substrates as behavioral manifestations (Merz et al., 2018). Impulsivity is an externalizing property of the psyche, manifesting itself in quick, thoughtless reactions about the consequences, in contrast to internalizing disorders like anxiety, where the manifestations are internal in nature (Beauchaine et al., 2017; Holmes et al., 2016).

General neurobiological mechanisms of impulsivity and anxiety are comorbid to internalizing and externalizing disorders. Impulsivity, manifested as disturbances in executive functions (such as working memory, inhibitory control, task switching), is also associated with anxiety (Taylor et al., 2008).

Traditional concepts suggest that impulsivity may show a negative correlation with anxiety (Perugi et al., 2011). Some studies support the suggestion that anxiety may affect impulsivity in individuals with a predisposition to behavioral disinhibition. Taylor et al. suggested that anxiety may serve as a protective factor against disinhibited, potentially harmful actions that could lead to negative outcomes (Taylor et al., 2008). However, a more recent study showed that increased anxiety in patients with bipolar affective disorder increases their level of impulsivity, which can complicate the disease (Corekcioglu et al., 2021). Nevertheless, there are solid evidences that anxiety influences the level of impulsivity. For example, certain types of anxiety affect the manifestation of increased impulsivity (Kashdan et al., 2009). Summerfeldt, Hood, Anthony, Richter and Swinson (2004) found that patients diagnosed with obsessive-compulsive disorder, panic disorder, and social phobia showed increased levels of impulsivity compared to controls (Summerfeldt et al., 2004). Bellani et al. (2012) reported that the presence of anxiety increases impulsivity in patients with affective and personality disorders (Bellani et al., 2012). Up to half of children with ADHD have a comorbid mood disorder (Zisner, Beauchaine, 2016). In addition, the presence of anxiety in mood disorders has been shown to increase impulsive behaviors such as suicidal thoughts, attempts, and completed suicides (Fava et al., 2004). Moreover, the increased impulsivity could accelerate suicidal thoughts by decreasing internal inhibition (Schaefer et al., 2012).

There are diverse positions on the definition of impulsivity (Arce, Santisteban, 2006; Bakhshani, 2014; Dickman, 1990; Evenden J.L., 1999; Eysenck, Eysenck, 1975). The precise definition of the term "impulsivity" varies widely across studies. In general terms, the manifestation of impulsivity is associated with poor self-control and can refer to actions that are risky, prematurely expressed, and poorly comprehended (Dalley et al., 2011; Durana et al., 1993; Evenden J., 1999; Winstanley et al., 2006).

In psychology, impulsivity is a multidimensional construct consisting of various psychological elements: impaired response inhibition (motor impulsivity), hypersensitivity to reward anticipation (reward impulsivity), and poor planning (cognitive impulsivity), which in turn have different neurobiological mechanisms (Fineberg et al., 2010; Grant, Kim, 2014; Robbins et al., 2012).

Motor impulsivity is defined as the inability to suppress dominant reactions and is most likely associated with a deficit in behavioral inhibition. Reduced motor inhibitory control is characterized by poor ability to suppress unproductive behaviors or cognitive processes (Roberts et al., 2011). A large number of studies of impulsivity involve the use of neuropsychological tests. The two most common behavioral tests to measure motor impulsivity are the Go/No Go task and SSRT (stop signal reaction time task). "High" impulsive individuals were reported to perform worse on decision tests (Crean et al., 2000; Franken et al., 2008) and had longer latency when performing SSRT (Logan et al., 1997). Impulsivity deficit in the SSRT is modulated by norepinephrine (Padhi et al., 2012). The level of impulsivity may depend on a number of errors that indicate the inability of a person to suppress unplanned reactions (Fillmore, 2003).

Reward impulsivity refers to the depreciation of a larger reward with increasing latency. People with a high level of impulsivity are willing to take a little, but now, rather than more at a later time (MacKillop et al., 2011). The most often tests measuring reward impulsivity are the Iowa Gamble Task and the Cambridge Task. Reward impulsivity deficits have been found in a number of addictive behaviors and can be modulated by dopamine and serotonin.

Cognitive impulsivity refers to making choices in the condition of insufficient information. Impulsivity is associated with attention dysfunction (Bari, Robbins, 2013; Dalley et al., 2011) and the inability to follow instructions (Kozak et al., 2019). Difficulty maintaining attention was also observed in increased impulsivity (Levine et al., 2007). The study of school readiness and achievement found that children who can restrain impulsive behavior and be attentive make better use of learning opportunities in school (Duncan et al., 2007). This type of impulsivity can be measured using the "Reflection Task" (Padhi et al., 2012). Measures of impulsivity, especially behavioral measures, showed that highly impulsive individuals reacted more slowly (Robinson et al., 2009). Difficulty maintaining attention underlying impulsivity (in the context of drug use) was characterized by longer reaction times due to loss of attention while performing tasks (de Wit, 2009; Enticott et al., 2006).

Similar results are described in studies of impaired oculomotor control. Besides data on reaction times, research in oculomotor control could be a complementary approach to studies of impulsivity. Oculomotor and manual motor inhibitory controls act differently, both anatomically (Aron et al., 2004) and functionally (Nigg, 2000). For example, the region of the frontal eye field (FEF) is involved in the inhibition of saccadic eye movements (Schall et al., 2002), rather than other manual motor actions (Chevrier et al., 2007). Children with ADHD showed greater impairment of oculomotor inhibitory control compared to manual motor inhibitory control (Adams et al., 2010; Logan, Irwin, 2000). Several studies have provided behavioral evidence for the independence of these systems: manual inhibitory control differed from oculomotor inhibitory control in a simple activation time, and these inhibitory processes were differentially affected by task manipulation (Adams et al., 2010; Logan, Irwin, 2000). In addition, in contrast to manual inhibitory control, the processes of oculomotor inhibitory control are closely related to the distribution of attention (Godijn, Theeuwes, 2003). The ability to effectively suppress saccades towards ignored stimuli is important for the effective execution of goal-directed actions. Due to the fact that the oculomotor system mediates motor and cognitive control, measurements of oculomotor responses can provide important information about the neurophysiological mechanisms associated with cognitive functions (Henderson et al., 2013; Leigh, Zee, 2015). Additionally, studies of the motor and cognitive context of impulsivity could be carried out using various designs to eliminate the effect of training, assess the switching of attention from one task to another, and the effectiveness of task completion (Munoz et al., 2003).

The oculomotor reactions in children with ADHD, who have impulsiveness as a key feature of the disorder, manifest themselves in the form of abnormalities in the control of saccadic eye movements, difficulties with visual fixation, and disturbances in smooth-pursuit movements (Cairney et al., 2001; Janmohammadi et al., 2020; Munoz et al., 2003; Pishyareh et al., 2015). Studies of eye-movement patterns in ADHD may provide valuable information about the neurophysiological correlates of impulsivity. Previous results on a delayed ocular response task (DORT) and a visual stopping task showed a negative correlation of inhibitory control in eye movements with the level of impulsivity in ADHD (Roberts et al., 2011). Additionally, oculomotor inhibition is also critical for supporting directional attention to appropriate stimuli and the ability to effectively ignore irrelevant, distracting stimuli (Houghton, Tipper, 1994).

An anti-saccade task could be the most effective neurobiological paradigm for studying impulsivity as this task helps to measure the functions of inhibitory control and attention (Hutton, Ettinger, 2006). In the anti-saccade task, participants must look in the opposite direction from the presented visual stimulus (Munoz et al., 2003). The anti-saccade performance depends on the functioning of the dorsolateral prefrontal cortex (DLPFC), an area responsible for top-down control that suppresses reflective prosaccade in response to visual stimuli (Hutton, Ettinger, 2006). Individuals with ADHD also demonstrated more premature saccades, fewer corrective saccades on reading tasks, and more errors on anti-saccade tasks than controls (Karatekin, 2007). The study of hyperactive behavior measuring errors and the presence of anticipatory saccades reported that premature anticipatory eye movements were positively associated with inattentive traits in ADHD while no relationship was found between mistakes and ADHD personal traits (Siqueiros Sanchez et al., 2020). The study by Lev et al. also observed inattention in patients with ADHD, which was reflected in a significantly longer time spent looking at irrelevant areas both on and off the screen than in healthy controls (Lev et al., 2022). Some studies reported that children with ADHD showed significantly greater saccade latency in the anti-saccade task (Goto et al., 2010; Munoz et al., 2003) and lower accuracy in prosaccades as compared with typically developing (TD) children (Goto et al., 2010; Huang, Chan, 2020). Eye movement disorders have also positively correlated with the severity of ADHD symptoms (Manoli et al., 2021). Therefore, interventions associated with eye movement abnormalities in children with ADHD are of clinical importance (Lee et al., 2020).

Emotional regulation also affects inhibitory control and may cause impairment. The type of emotional valence in images (pleasant, unpleasant, neutral) affects eye movements during visual search, its control, as well as the duration of the gaze (Pishyareh et al., 2015). Difficulty in inhibitory control with the presentation of emotional stimuli was reflected in lower accuracy in the presence of angry faces than in neutral ones; latency of saccade was longer for angry faces than for neutral ones in the prosaccade trials, but the opposite result occurred in the anti-saccade tasks (Llamas-Alonso et al., 2020), suggesting that negative facial expressions require more effort to achieve inhibitory control and voluntary reorientation of attention.

Impulsivity, manifested in the difficulty of suppressing certain actions, is often associated with increased anxiety. This study aimed to trace the neurophysiological markers of different levels of impulsivity in highly anxious individuals using eye-tracking method. Depending on the level of impulsivity, individuals with higher anxiety react differently to tasks requiring inhibitory control such as anti-saccade task. There are different designs of anti-saccade task, but the main ones are step, gap and overlap types. Each task design showed specific results for certain features of eye movements in the ADHD samples (Goto et al., 2010; Munoz et al., 2003; Siqueiros Sanchez et al., 2020). Our purpose was to apply the main types of experimental paradigm design and see how the results differ depending on the specificity of the anti-saccade task. We tested a hypothesis that eye-movement patterns during anti-saccade tasks presented with different designs would differ between anxious individuals with high and low trait impulsivity. Previous studies have been conducted on samples with mental disorders with high levels of impulsivity in behavior. Importantly, we focused on the comparison of eye movements in the sample of participants without a diagnosis of mental illness. To test the possible effect of emotions on inhibitory control of eye movements in high anxiety, we applied pictures with negative, positive, and neutral emotional valence in the anti-saccade tasks. This field of research could be advantageous to develop a psychophysiological assessment of impulsivity at a young age for the early detection of possible mental disorders.

2. METHODS

2.1. Participants

Thirty-four volunteers (26 females, 8 males) were recruited via the student program of participation in psychological research projects at the National Research University High School of Economics. Participants were all right-handed. The exclusion criteria were the following: (i) history of substance abuse; (ii) mental disorders or neurological impairment; (iii) uncorrected vision. The mean age of the sample was 20.2 ± ± 0.6 years old.

The study was carried out in the Core Facility Center of the Institute of Higher Nervous Activity and Neurophysiology of the Russian Academy of Sciences.

2.2. Ethical statement

All experimental procedures complied with the requirements of the Helsinki Declaration. The ethical committee of the Institute of Higher Nervous Activity and Neurophysiology of the Russian Academy of Sciences approved the study protocol (#0125022021). All participants gave written informed consent before their participation in the study.

2.3. Psychological assessment

Participants filled in web-forms with questionnaires based on Russian versions of the State-Trait Anxiety Inventory (STAI) and Barratt Impulsiveness Scale (BIS-11).

State-Trait Anxiety Inventory (STAI) is a test developed by Charles Spielberg, R.L. Gorsuck and R.E. Lushene (adapted into Russian by Khanin, 1977) for assessing state and trait anxiety. The current study used the trait anxiety which explores a stable individual characteristic reflecting the individual predisposition to anxiety and suggesting that a person has or has not a tendency to perceive life situations as threatening, responding to each of them with a certain reaction. The trait inventory estimates self-reports how individuals feel across typical situations that everyone experiences on a daily basis (Heeren et al., 2018). The trait anxiety consists of 20 statements. All items are scored on a four-point scale, ranging from 0 (no symptoms) to 4 (extreme symptoms). The overall final score of trait anxiety can range from 20 to 80 points. The higher the score, the more serious the anxiety symptoms. In general, a total score of fewer than 30 points indicates mild symptoms, 30–44 points indicate moderate symptoms, and more than 45 points indicate severe symptoms. The reliability and validity of the inventory were confirmed in many studies (Guillen-Riquelme, Buela-Casal, 2014; Julian, 2011).

Barratt Impulsiveness Scale (BIS-11) is also a self-reporting test developed Ernest S. Barrat in 1995 (Russian adaptation by Enikolopov, Medvedeva, 2015) for assessments of impulsiveness and its components (the first order: attention, motor, self-control, cognitive complexity, perseverance, cognitive instability; the second order: attention, motor, non-planning) (Patton et al., 1995). The questionnaire consists of 30 statements, which assess the overall impulsivity score and score of its separate components. All items are scored on a four-point scale, ranging from 0 (no symptoms) to 4 (extreme symptoms). The overall final score of impulsiveness can range from 30 to 120 points. A total score of fewer than 70 points indicates a lack of increased impulsivity, 70–75 points indicate the presence of increased impulsivity, and more than 75 points indicate the presence of highly elevated impulsivity (violation of impulsivity control). The BIS-11 scale has good reliability and validity (Chowdhury et al., 2017; Osher et al., 2019).

According to the psychological assessment, participants were divided into 2 groups: LI&HA –

Table 1. The group descriptive statistics
Таблица 1. Описательная статистика групп

Test Score	Low Impulsivity & High Anxiety*	High Impulsivity & High Anxiety*
State-Trait Anxiety Inventory	51.3 ± 4.8	50.9 ± 10.1
Barratt Impulsiveness Scale	59.7 ± 7.4	74.9 ± 4.5
Mean age	20.2 ± 0.5	20.2 ± 0.9

Note: * values represent means and standard deviations.
Примечание: * значения представлены в виде “среднее значение ± стандартное отклонение”.

20 individuals (15 females, 5 males) in the group with a low level of impulsivity and high level of anxiety (mean age: 20.2 ± 0.5 years old), and HI&HA – 14 individuals (11 females, 3 males) in the group with a high level of impulsivity and high level of anxiety (mean age: 20.2 ± 0.9 years old). Table 1 contains the group scores of state anxiety and impulsivity according to STAI and BIS-11 and the mean age for both groups.

2.4. Procedure and eye-movement data acquisition

Two days before the experimental procedure, participants obtained the preliminary screening tests on inclusion in the study in electronic form. Upon arrival at the research facilities, participants signed informed consent and consent to the processing depersonalized data. After that, a clinical psychologist (G.K.) examined the participants using the structured clinical interview and later they fulfilled the STAI and BIS-11. The experiment was carried out in an eye-tracking lab equipped with a soundproofing dark room to keep consistent lighting conditions. Each participant got acquainted with the laboratory and passed the test version of the paradigm. Subsequently, the participants were asked to sit in a chair in front of a computer monitor.

Before the eye tracking experiments, ocular dominance was assessed using the hole-in-the-card test (Dolman method) (Cheng et al., 2004). In this test, the participant was instructed to hold a piece of cardboard with a central circular hole through which they had to view a target at about 6 m away with both eyes open. Subsequently, each eye was occluded in turn. The target would not be seen through the hole when the dominant eye was covered; on the contrary, the target persisted to be seen when the non-dominant eye was covered since the dominant eye would continue to fix the target. In this forced-choice test of dominance, there was only one result for dominance (left or right). The eye movement data were recorded using the dominant eye to avoid the potential confounding effect of differential dominance on eye tracking measures (Vergilino-Perez et al., 2012).

Eye-movement data were recorded by the eye tracker Eyelink Portable Duo (Sr Research Ltd., Canada) with a sampling rate of 500 Hz. The participant’s chin was comfortably fixed on a head mount to ensure stability. The 20″ flat screen monitor (Asus Vision XG248q, 240 Hz) had a resolution of 1152 × 864 pixels and was positioned 70 cm from the participant. All participants have got detailed instructions on how to perform a task. During the experiment, participants were asked to try to keep their heads as still as possible. Calibration and validation procedures were performed immediately before the task block. The participants were asked to visually follow a white dot moving in different places on the screen 9 times. The calibration time was about 30 s. Validation was carried out according to the same technical principles as calibration. If the accuracy was poor (fewer than 0.5°), recalibration was performed. The experiment was only started if the participant successfully passed the calibration and validation procedures. After that, the task instruction appeared on the screen depending on the block design. After completing each block, the participant could rest for about 10 min. Before proceeding with the next block, the participant passed again the calibration and validation procedure. Overall, it took participants about 50–60 min to complete the experiment.

2.5. Anti-saccade tasks

The paradigm was set using Eyelink Experiment Builder 2.3.1 software (Mississauga, Ontario, Canada: SR Research Ltd., 2020). The paradigm consisted of three blocks of anti-saccade tasks (Subramaniam et al., 2018; Taylor, Hutton, 2009) with different timing designs between central fixation and target stimuli: block 1 – Step; block 2 – Overlap; block 3 – Gap. Each participant performed a total of 300 anti-saccade trials in all three blocks. Each block contains 100 trails,

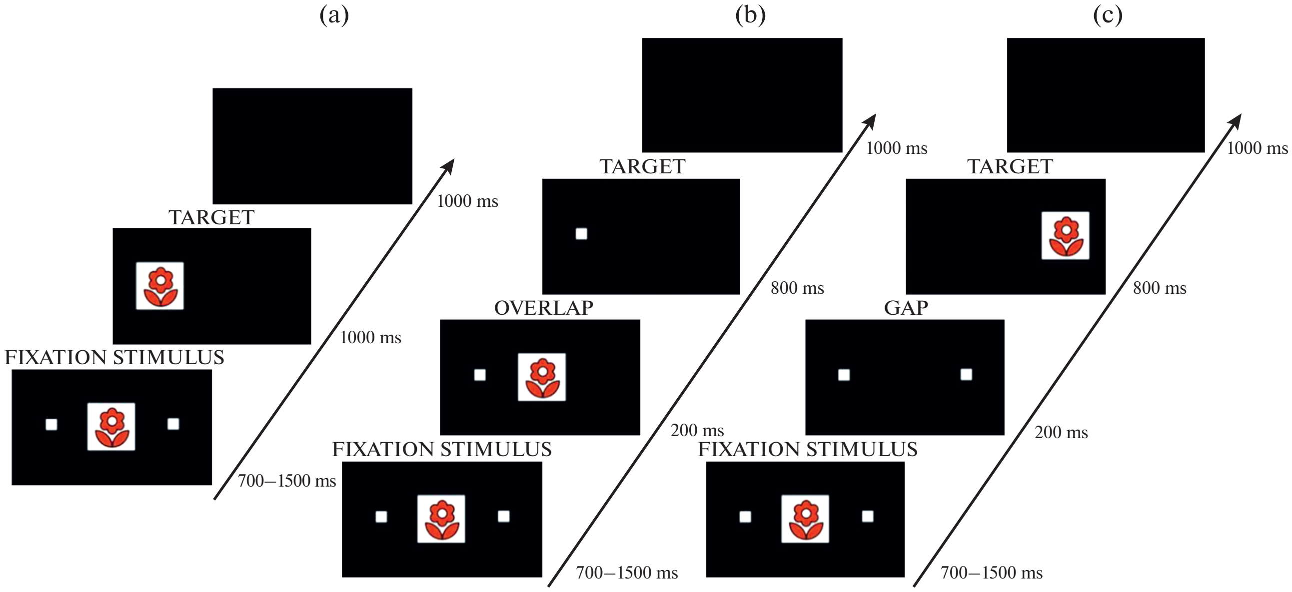

Fig. 1. The study paradigm with stimuli. (a) Step design. (b) Overlap design. (c) Gap design. The flower picture is a substitute of image taken from IAPS.
Рис. 1. Парадигма исследования со стимулами. (a) “Step” дизайн. (b) “Overlap” дизайн. (c) “Gap” дизайн. Изображение цветка является заменой изображений, взятых из IAPS.

of which 60 trails are pictures (the fixation stimuli) of neutral valence, 20 trials – positive valence, and 20 trials – negative valence. Positive and negative images were taken from the International Affective Picture System (Lang et al., 2008). The neutral stimuli represented as gray circle (RGB: 128, 128, 128). All images were squares 250 × 300 mm, and the target stimuli were small squares 14 × × 14 mm which were on both sides of the fixation images. The selected positive stimuli had a mean valence of 7.40 ranged 7.0–7.8, and a mean arousal of 4.9 ranged 4.2–5.6. The selected negative pictures had a mean valence of 2.2 (1.7–2.7) and a mean arousal of 6.1 (5.4–6.8). A circle serves as the neutral stimulus, which did not change in all presentation blocks. The stimuli for each trial appeared on a screen with a black background.

Figure 1 illustrates three blocks of experimental paradigm. The first block consisted of the antisaccade task with the Step design, the second block – Overlap, and the third – Gap. The fixation stimulus of each block comprised the pictures (neutral, positive, negative). Each trial began with a central fixation stimulus, which remained on screen for between 700–1500 ms. On both sides of the central fixation stimulus, there were 2 small squares. After an interval (700 to 1500 ms; interval occurring randomly, – in order to prevent the participants from the additive effect, which could affect the results.), at the Step design, the target stimulus appeared at two possible locations, ±6° of visual angle from the center. The target stimulus was the same picture as the central fixation stimulus, which lasted for 1000 ms. The instruction to the individuals for the step task was to look at the mirror image location of the target without looking at the target itself (fig. 1 (a)).

At the Overlap design of the anti-saccade task, the target stimulus was one of the 2 small squares standing at both sided of the central fixation stimulus. After the interval 700–1500 ms as in the Step design, only the fixation stimulus with one square on one side remained on the screen, and the second square disappeared. After 200 ms the central fixation stimulus disappeared while the square was left on one side of the screen. The target stimulus (the square) lasted for 800 ms at two possible locations, ±6° of visual angle from the center. The instruction to the individuals for the overlap task was to look at the mirror image location of the remaining square (fig. 1 (b)).

At the Gap design, the central fixation stimulus and the target stimulus comprised emotional pictures (neutral, positive, negative). After the interval 700–1500 ms as at Step and Overlap design, the central fixation stimulus disappeared, the participant observed empty black screen during 200 ms. After the 200 ms gap, the target stimulus appeared on one of the sides. The target stimulus was the same picture as the central fixation stimulus and lasted for 800ms. This target appeared at two possible locations, ±6° of visual angle from the center. The instruction to the individuals for the gap task was to look at the mirror image location of the target without looking at the target itself (fig. 1 (c)). After the participant performed the task, a black screen appears in all blocks (break between trails) at 1000 ms (fig. 1).

2.6. Data analysis

Data preprocessing was conducted using DataViewer (SR Research). Trials with artifacts (blinks, etc.), anticipated saccades, and trials with response latency less than 60 ms were excluded from the analysis. Further analysis was performed in RStudio (https://www.rstudio.com/). Data were divided into trials with correct anti-saccades and trials with error saccades (the initial saccade eye movement was directed toward the target stimulus – prosaccade). Error saccades with response latency from 90 to 140 ms were referred to as express errors and with latency more than 140 ms as regular errors.

The following parameters were measured for all participants in both groups for each type of emotional stimulus within three timing design types:

· anti-saccade regular error rate defined as the number of regular error trials over the total number of trials for each modality and multiplied by 100%;

· anti-saccade express error rate defined as the number of express error trials over the total number of trials for each modality multiplied by 100%;

· mean latency for correct anti-saccades;

· mean latency for express and regular error saccades toward the target;

· mean amplitude for correct anti-saccades;

· mean amplitude for express and regular error saccades toward the target;

· mean velocity for correct anti-saccades;

· mean velocity for express and regular error saccades toward the target.

2.7. Statistical analysis

The Shapiro–Wilk test was used to verify the normal distribution of samples. F-test was used to compare the variances of two samples from normal distributions. Depending on the normality of distribution between-group age and self-reporting test difference was compared using independent samples t-test (for BIS-11) and Mann-Whitney test (for STAI and age difference) between the groups. Statistical analysis of eye tracking measures was conducted in both groups for each parameter for each type of emotional stimulus within three design types. In the case of the normal distribution, the studied parameters were compared by an analysis of variance (ANOVA). The ANOVA design used 2 levels of between-group comparison (participants with LI&HA versus participants with HI&HA), 3 levels of blocks (Step versus Overlap versus Gap), and 3 levels of the stimuli modality (neutral, positive, and negative). If the ANOVA showed a significant effect, the Tukey Honestly Significant Differences (Tukey's HSD test) pairwise comparison was applied as a post hoc comparison.

If samples did not have the normal distribution, the Kruskal–Wallis test and then Dunn's test was used as a nonparametric equivalent of ANOVA and Tukey's HSD test as a post hoc respectively. The Friedman test was applied for intergroup post-hoc comparison to reveal any influence of block order of the anti-saccade paradigm on eye-tracking parameters. Only results of statistical tests passed the p-value threshold of 0.05 are reported.

3. RESULTS

The groups (LI&HA vs. HI&HA) did not differ significantly in the age distribution (20.2 ± 0.5 vs. 20.2 ± 0.9 years; $p > 0.05$) and in the trait anxiety distribution (51.3 ± 4.8 vs. 50.9 ± 10.1, $p > 0.05$). The level of impulsivity significantly differed between groups (59.7 ± 7.4 vs. 74.9 ± 4.5, $t = 7.45$, $p < 0.001$).

The obtained eye tracking data had variability in making directional errors in both groups without any intergroup and intragroup dependence on the design or emotional valence of the stimuli. The percentage of express errors was within the population range (<25%) in all blocks among all groups (Maruff et al., 1999). The percentage of regular errors was also within the population range in the Step and Gap design blocks for both groups, while the percentage of directional errors in the Overlap block exceeded the population values in both groups.

The full tables with values for all oculomotor parameters for three blocks are given in the Supplementary data 1. The studied eye-movement patterns did not differ between the stimuli valence and groups in the Step design.

In the Overlap design, only the regular error mean latency varied significantly among the

Table 2. Mean and standard deviation of the regular error latency for the overlap design
Таблица 2. Значения латентности саккад при совершении регулярных ошибок в overlap дизайне

Stimulus	Positive		Negative		Neutral*	
Statistic	M	SD	M	SD	M	SD
Low Impulsivity &High Anxiety (n = 20)	198.9	28.32	201.65	60.86	205.19	24.94
High Impulsivity &High Anxiety (n = 14)	226.71	56.89	231.54	40.29	231.74	38.9

Note: M – mean, SD – standard deviation, * p-value < 0.05.
Примечание: M – среднее значение, SD – стандартное отклонение, * p-значение < 0.05.

Table 3. Mean and standard deviation of the regular error amplitude for the gap design
Таблица 3. Значения амплитуды саккад при совершении регулярных ошибок в gap дизайне

Stimulus	Positive		Negative		Neutral*	
Statistic	M	SD	M	SD	M	SD
Low Impulsivity &High Anxiety (n = 20)	1.88	2.76	1.99	2.49	4.36	1.50
High Impulsivity &High Anxiety (n = 14)	1.17	2.29	1.38	1.76	3.14	1.67

Note: M – mean, SD – standard deviation, * p-value < 0.05.
Примечание: M – среднее значение, SD – стандартное отклонение, * p-значение <0.05.

groups in the trials with neutral stimuli ($p = 0.02$). Means and standard deviations are given in Table 2. The regular error mean latency was significantly longer for individuals with high impulsivity as compared with participants with low impulsivity ($p = 0.0105$ according to Tukey's HSD test) (fig. 2 (a)).

In the Gap design, the regular error mean amplitude varied significantly among the groups ($p = 0.033$) in response to the neutral stimuli. Means and standard deviations are given in Table 3. The regular error mean amplitude was significantly larger for individuals with low impulsivity compared with the group with high impulsivity ($p = 0.033$ according to Tukey's HSD test) (fig. 2 (b)).

A comparison of blocks showed that eye-movement patterns differed for the Overlap design for all participants. The amplitude, velocity and latency of correct anti-saccades in Overlap block were significantly lower than in the other designs ($p < 0.001$ according to Tukey's HSD test). In opposite, express and regular error rates,

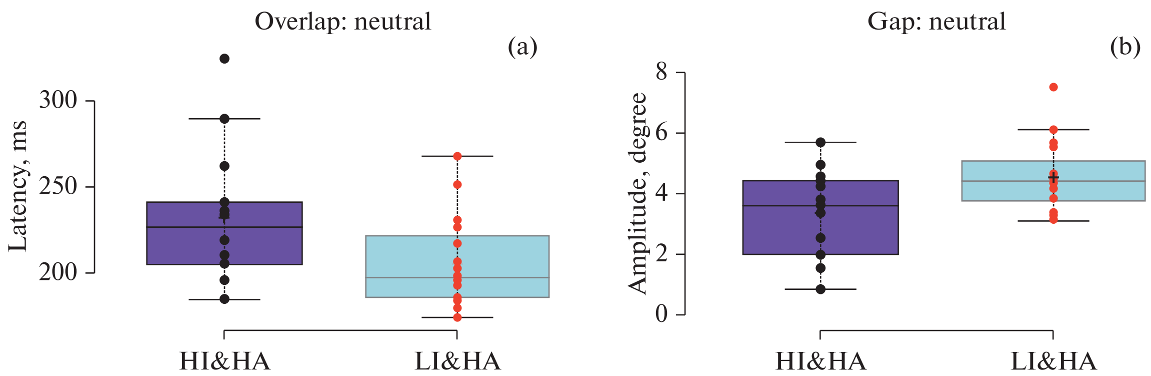

Fig. 2. Between-group comparison of saccade parameters in the trials with neutral stimuli. (a) Mean latency for regular error saccades in the Overlap design. Latencies significantly differ within both groups ($p < 0.5$). (b) Mean amplitude for regular error saccades in the Gap design. Amplitudes significantly differ within both groups ($p < 0.5$). HI&HA – high impulsivity and high anxiety group, LI&HA – low impulsivity and high anxiety group.
Рис. 2. Межгрупповое сравнение параметров саккад в пробах с нейтральными стимулами. (a) Средняя латентность для регулярных ошибок в "Overlap" дизайне. Латентность достоверно различается в обеих группах ($p < 0.5$). (b) Средняя амплитуда регулярных ошибок в "Gap" дизайне. Амплитуда значимо различается внутри обеих групп ($p < 0.5$). HI&HA – группа с высокой импульсивностью и высокой тревожностью, LI&HA – группа с низкой импульсивностью и высокой тревожностью.

the express error mean amplitude, the regular error mean amplitude, latency and velocity were higher than in the other blocks ($p < 0.001$). Moreover, values of express error mean latency ($0.001 < < p < 0.01$) and express error mean velocity ($0.001 < p < 0.05$) were the largest for Overlap design and the lowest for Step design.

The Friedman test did not reveal any impact of the block order of the anti-saccade paradigm on the saccade parameters within the high impulsivity group. The task order significantly influenced the express error mean latency in response to the positive stimuli within the low impulsivity group ($p = 0.03$).

4. DISCUSSION

High anxiety and high impulsivity frequently co-occur and affect behavioral responses to emotional stimuli, especially in tasks requiring inhibitory control. We tested the hypothesis that high impulsivity (HI) might influence performance and eye-movement patterns in anti-saccade tasks with target stimuli of different emotional valence in individuals with higher anxiety (HA). For this, we compared the error rate, latency, amplitude, and velocity of correct and erroneous saccades between two groups of participants: HI&HA group and LI&HA group. To induce stronger involvement of inhibitory control, modulate attention engagement, and prevent the effect of addiction and learning, we applied three timing designs of anti-saccade tasks: Step, Gap, and Overlap. We observed a significant increase in latencies of regular error saccades on neutral stimuli in the Overlap block in the group with high impulsivity and high anxiety. This result is partially consistent with previous findings showing that participants with ADHD and OCD with high impulsivity, performed an anti-saccade task with increased anti-saccade latency compared to controls (Goto et al., 2010; Hakvoort Schwerdtfeger et al., 2012; Hu et al., 2020; Sekaninova et al., 2019). The increase in anti-saccade latency reflects the additional time processing required to inhibit the reflective saccade towards the peripheral stimulus and change the saccade program to make the antisaccade (Maruff et al., 1999). A deficit in saccadic suppression is considered to be one of the main reasons for eye-movement impairment (Hakvoort Schwerdtfeger et al., 2012; Liang, 2018; Munoz et al., 2003; Roberts et al., 2011). An imbalance between voluntary and automated saccadic impulses leads to the initiation of regular latency direction errors (Coe, Munoz, 2017). However, in our study, the higher impulsivity group did not show a significant effect on the anti-saccade latency or increased number of errors compared to the low impulsivity group. Between-group differences were observed only for the latency of erroneous saccades in response to neutral stimuli. As participants of both groups had increased trait anxiety, we may assume that observed differences in latencies of regular errors reflect specifically a combination of increased anxiety and impulsivity. Especially since the mechanisms of inhibitory control deficits in high anxiety could be the same as in high impulsivity (Liang, 2018).

In the studies of Liang et al., 2018 and Blekic et al., 2021 participants with high anxiety performed anti-saccade tasks and demonstrated correct anti-saccades with longer latency compared to controls, while the number of directional errors depended on the design of the paradigm. Our study partially reproduces these results as we showed that the error rate exceeds 25% only in the Overlap block. In the anti-saccade task, rash intention to solve the task as soon as possible, which is inherent in impulsive behavior (Levine et al., 2007), is reflected in decreased attention to the fixation stimulus and immediately following of the gaze towards or opposite to the target stimulus. Therefore, highly impulsive individuals have less difficulty shifting attention in rapidly changing conditions, such as in the Step and Gap blocks. The Overlap design allows participants to know the target stimuli in advance, but the response must be given later. Anticipation of the right time to give the response inhibits the attention shift, increasing the time for making a decision, especially where there is no emotional context. Attention dysfunction is one of the components of impulsive behavior (Bari, Robbins, 2013; Dalley et al., 2011). In the case of presentation of neutral stimuli in the Overlap block of the anti-saccade task, we observed an increase in regular error latency in the group with high impulsivity and high anxiety compared with low impulsive individuals with higher anxiety. The low semantic content of neutral stimuli might lead to a decrease in the concentration of attention associating with prolonged latencies of errors in higher impulsive individuals.

It was previously reported that correct anti-saccade and error saccade amplitude was decreased in different psychological disorders. For instance, patients with diagnosed OCD performed anti-saccade tasks with shorter saccade amplitude compared to controls (Ray et al., 2019). Patterns of antisaccades and their relation to structural changes in the cerebral cortex were studied by Ettinger et al., 2004 in the first-episode psychosis patients showed reduced saccade amplitude and a positive correlation between its amplitude and the caudate volume (Ettinger et al., 2004). We observed that participants with high impulsivity made regular error saccades on neutral stimuli with decreased amplitude in the Gap block as compared with low impulsive individuals. The decreased amplitude of erroneous saccades in the Gap design could also reflect impulsive behavior.

Our results support previous finding showing effect of Overlap and Gap at patterns of eye-movements in the anti-saccade tasks on neutral stimuli. We did not observe the group differences in eye-movement patterns in response to emotional stimuli. The absence of differences could be explained by similarity of the anxiety level, which could affect reactions to emotional stimuli, in both groups (Chen et al., 2014; Mueller et al., 2012). However, the impulsivity level modulated responses to neutral stimuli. The timing design allows modulating engagement of attention and inhibitory control (Klein et al., 2000; Munoz et al., 2003). In the Overlap tasks, the latency of regular errors to neutral stimuli in highly impulsive individuals could increase due to the long duration of the fixation stimulus on the screen and the absence of changing events, which, in turn, reduces the concentration of attention. In the Gap task, with changing events on the screen (appearance of the target stimulus and disappearance), highly impulsive participants, even making a mistake, could quickly turn on and redirect the saccade in the right direction, which may indicate that a high level of impulsivity does not always have a negative effect on performance. Decision-making in impulsivity can be not only inefficient, as indicated in most studies, but also highly effective both in terms of speed and quality of the task solution. In further research, we would propose to classify impulsive persons by efficiency based on primary neuropsychological tests.

5. CONCLUSIONS

Our work reveals new details about eye movements not only for anxious and impulsive individuals separately but also for ones with both personal traits. All participants had a high level of trait anxiety but different levels of impulsivity. Significant differences were observed between groups in the regular error mean latency in the Overlap block and the regular error mean amplitude in the Gap block. The Overlap effect caused longer latencies of erroneous saccades while the Gap effect produced lower amplitudes of erroneous saccades in the group with increased trait impulsivity in the tasks where neutral stimuli were used either as fixation or target stimuli. Our findings imply that different designs of the anti-saccade task can reveal specific patterns of eye movements associated with attention switching and inhibitory control in impulsive behavior in the condition of high anxiety.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials: https://jvnd.ru/supplemental-materials/

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ОСОБЕННОСТИ ГЛАЗОДВИГАТЕЛЬНЫХ РЕАКЦИЙ У ВЫСОКОТРЕВОЖНЫХ ДОБРОВОЛЬЦЕВ С РАЗНЫМ УРОВНЕМ ИМПУЛЬСИВНОСТИ ПРИ РЕШЕНИИ РАЗНЫХ ВАРИАНТОВ АНТИСАККАДНОЙ ЗАДАЧИ

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Введение. В зависимости от уровня импульсивности лица с повышенной тревожностью по-разному реагируют на задачи, требующие тормозного контроля. Антисаккадная задача является одним из психофизиологических подходов к оценке зрительного внимания и тормозного контроля. Это исследование было направлено на проверку гипотезы о том, что люди с высоким уровнем импульсивности и тревожности будут иметь разные модели движения глаз в задаче на антисаккады по сравнению с людьми с высокой тревожностью и низким уровнем импульсивности. **Метод.** В исследовании двадцать добровольцев с высоким уровнем тревожности и низким уровнем импульсивности и четырнадцать человек с высоким уровнем тревожности и импульсивности выполняли антисаккадные задачи в трех блоках, которые отличались способами разделения по времени появления целевого стимула (step, overlap, gap) с фиксационными и целевыми стимулами негативной, позитивной и нейтральной модальностей. Глазодвигательные паттерны записывались методом айтрекинга. **Результаты.** Значительные различия наблюдались между группами в латентности регулярных ошибок в overlap-последовательности и в амплитуде регулярных ошибок в gap-последовательности. Лица с высокой тревожностью и высокой импульсивностью совершали регулярные ошибки с большей латентностью в overlap-блоке и с меньшей амплитудой в gap-блоке только на нейтральные стимулы. **Заключение.** Наши результаты показывают, что различные схемы антисаккадной задачи способны выявлять специфические паттерны движений глаз, связанные с переключением внимания и тормозным контролем при импульсивном поведении.

Keywords: антисаккадная задача, айтрекинг, импульсивность, тревожность, тормозной контроль