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ORIGINAL ARTICLE

COMPARISON OF RANDOM SACCADE TEST AND CLINICAL SACCADOMETRY TEST RESULTS OF HEALTHY ELDERLY AND YOUNG INDIVIDUALS

Abstract

Introduction: The effects of aging on oculomotor functions and higher-level cognitive processes are increasingly being investigated, and saccadic eye movements are considered an important tool to evaluate these changes related to aging. The aim of our study is to compare the random saccade and clinical saccadometry test parameters of healthy young and elderly participants.

Materials and Method: The study included two healthy adult groups, Group I (Young adults (18–30 years)) and Group II (Elderly adults (65–80 years)). Participants were administered random saccade test and prosaccade and antisaccade tests with the newly developed clinical saccadometry protocol, respectively.

Results: A total of 71 participants were included in the study, 37 in group I and 34 in group II. Random saccade latency in group I was determined to be significantly earlier compared to group II ($p<0.05$). Prosaccade and antisaccade latencies in group I were found to be earlier, while prosaccade and antisaccade directional error rates in group I was lower compared to group II ($p<0.05$). There was no significant difference between the groups in terms of velocity and accuracy parameters.

Conclusion: Our results suggest that age-related changes affect certain oculomotor functions, while some parameters remain stable in healthy aging. These findings enhance our understanding of oculomotor aging; however, further research is needed to assess their clinical relevance. Additionally, saccadometry may help elucidate cognitive and neural mechanisms in aging and serve as a potential tool for differential diagnosis.

Keywords: Saccade; Aging; Eye Movements; Cognition.

INTRODUCTION

Saccades are rapid conjugated eye movements that enable fast focusing of environmental targets on the fovea (1). They are evaluated using the parameters of latency, velocity, and accuracy. Latency is the duration of time from the appearance of the target to the onset of the saccades, which is between 170-350 ms in healthy subjects (2, 3). Velocity refers to the maximum speed achieved during eye movement and can range from 50° to 700°/second in adults. Average values above 230°/second are considered normal. Accuracy indicates how accurately and appropriately the eye moves toward the target. Scores above 70-80% gain are considered normal (3).

Measurement of saccadic eye movements can be useful as a biomarker, especially in the diagnosis and follow-up of neurodegenerative disorders. Thus, saccadic tests are valuable in facilitating the diagnosis. Saccadic tasks include prosaccade (PS), which aims to focus rapidly on the visual stimulus, antisaccade (AS) which is the movement that is in the opposite direction from the stimulus and involves more complex tasks such as memory-guided saccade, i.e., the movement towards the position of a subject that is no longer present (4). The function of AS pertains to the inhibition of a dominant visual-motor response, and it is a well-proven executive function test for aging and neurodegeneration (5).

Premotor circuits in the cerebellar reticular formation, frontal cortex, visual cortex, thalamus, basal ganglia, lateral geniculate ganglia, superior colliculus, and brain stem take part in the creation of AS and PS. That is the basis for the supposition that neurological dysfunction or degeneration may alter saccade performance (6). It has been proposed in the literature that AS test is useful in the evaluation of neurodegenerative disorders, especially Parkinson's disease and dementia (7, 8).

Saccadometry is a sophisticated ocular motor test that enables the functional evaluation of various brain regions and circuits that are active in the creation of rapid, appropriate, and task-specific saccadic eye movements. Saccadometry consists of PS and AS tests that provide useful information in locating the lesion and include the parameters of latency, velocity, accuracy, and directional error. These measurements that are utilized in the evaluation of saccadic and antisaccadic systems may also provide data pertaining to concussion, traumatic brain injury, neurodegenerative diseases, movement disorders, depression, attention deficit disorders, and other neurological disorders (9). Although there exist different saccadometry protocols for these patient groups in the literature (10-12), there is only one study that proposes a test that has been adapted for a clinical environment, and is simplified, time efficient, and tested on a healthy population (6). Demian et al. analyzed the saccadic alterations due to aging in 5 different age groups from a population of patients aged 18-69 years. They created a practical protocol by standardizing tests that utilize Video-Oculography (VOG) devices and that enable clinicians to use their standard equipment. Their protocol allows the evaluation to be completed in a period as short as minutes. In contrast to previous studies, the application of PS and AS tasks in different blocks and by turns prevents loss of attention and learning effect (6).

We did not encounter any study in the literature that included subjects from a wider age range, and which analyzed the results from both random saccade and the aforementioned new saccadometry protocol.

Although saccadometry has been explored as a potential biomarker in the diagnosis and monitoring of neurodegenerative disorders, this study aims to establish normative saccadic parameters in healthy individuals, providing a foundation for future research involving clinical populations. In this regard, we aimed to compare the random saccade and clinical saccadometry results between healthy

young adults (age range 18-30 years) and healthy elderly adults (65-80 years).

MATERIALS AND METHOD

Ethics committee approval

Ethical approval for this study was obtained from a local ethics committee for non-interventional clinical research (approval number: 1677). Informed consent forms were taken from every participant. This research was conducted in compliance with the principles of the Helsinki Declaration.

Study Design and Participants

This research was designed as a cross-sectional study. The study was conducted in two locations: the Audiology Unit of the Department of Otorhinolaryngology at Ege University Medical Faculty Hospital and the Otorhinolaryngology Clinic at Ankara Etlik City Hospital.

The research was carried out between August 2024 and November 2024. The study included the relatives of patients visiting the clinics at both centers, university and hospital staff, intern university students, and patients who met the inclusion criteria and presented various ailments at the outpatient clinic.

The study population was divided into two distinct age groups to evaluate age-related differences in saccadic eye movement parameters: Group I – Young Adults (aged between 18 and 30 years) and Group II – Elderly Adults (aged between 65 and 80 years).

The inclusion criteria were as follows: being in the age range of 18-30 or 65-80 years, being able to understand Turkish both in writing and verbally, understanding the test instructions and completing the tests, scoring at least 24 points on the Mini Mental State Examination (MMSE) for cognitive screening, and achieving a score of 0 on the Dizziness Handicap Inventory (DHI).

The exclusion criteria were as follows: Having a neuro-otological problem, having been diagnosed with vestibular diseases, having been diagnosed with psychiatric and/or neurological diseases, having advanced visual impairment and cognitive problems, regular medication use, and having a cognitive problem.

MMSE and DHI were administered to all participants on the same day before random saccade and saccadometry tests.

The projected sample size was derived based on the saccadometry test score, utilizing the paired Student's t-test with 80% power, an α value of 0.05, and a "large" Cohen's d effect size. Consequently, it was considered necessary to include at least 26 participants in each group. The groups consisted of 80 participants, including 40 individuals from each group. Three individuals from the group I and six people from the group II were excluded from the research due to their inability to adjust to the test. The study was concluded with a total of 71 participants.

Data Collection Tools

In this study, participants underwent a random saccade test and saccadometry test using the Micromedical VisualEyes™ 525 VNG device (Interacoustics A/S, Middelfart, Denmark). The participants wore videonystagmography (VNG) goggles to record eye movements.

They were seated on a fixed stretcher, 1 meter away from the stimulus monitor/TV screen where they could observe the light movements, and the height was adjustable. They were instructed to sit upright and wear VNG goggles to record their eye movements. After the prerequisites were met, the calibration stage was initiated. For VNG calibration, the participants were instructed to look straight ahead and keep their heads still, following targets moving on the horizontal and vertical axes only with their eyes. After the calibration phase, the random

saccade test and the saccadometry test were administered, respectively. All tests in the study were administered to the participants by the same doctor audiologists (G.K. and G.S.U.). The doctor audiologists administered all tests on the same day.

Random Saccade Test

The participants were instructed to follow a randomly illuminated target on the horizontal plane within the 5-30° range without head movement, and the test was concluded after a total of 30 jumps (15 to the right and 15 to the left). Eye movements were evaluated based on the parameters of latency, velocity, and accuracy.

Saccadometry Test

Each participant was administered the PS and AS tests, respectively. During these tests, the TV screen background was black, and the central target that was continuously lit in the center and the stimulus targets were chosen in red. During the PS test phase, the participants quickly moved their gaze from the central target to the stimulus target and swiftly returned to the central target upon the disappearance of the stimulus. In the AS test, the participants looked in equal and opposing directions from the stimulus target and quickly returned their gaze to the central target when the stimulus target disappeared. Each stimulus target was presented at a jump size of 10 degrees to the right or left of the center target on the screen following a random delay. The tests were performed on the horizontal plane at a 10° angle, and a total of 60 jumps were recorded (30 to the right and 30 to the left). The recording duration was determined at 151 ms for each test (6).

In the saccadometry test, the measurement parameters of velocity, latency, and directional error (DE) rate were evaluated. Velocity was measured in degrees/second, latency in milliseconds, and accuracy in percentages. In the PS test, the DE ratio is formed by the participant looking away from the stimulus, while in the AS test, it is formed by looking toward the stimulus (6). The averages of the right and left values in the test were included in the analysis.

Statistical Analysis

Statistical analyses were performed using the IBM SPSS software version 25.0. The normal distribution of the data was assessed with the Kolmogorov-Smirnov test. Parametric tests were used as parameters showed a normal distribution. Numerical data were presented using descriptive statistics. Comparison of numeric variables between groups was made using an independent samples t-test, and categorical variables were compared using a Chi-square test. A p-value lower than 0.05 was accepted as statistically significant.

RESULTS

A total of 71 participants were included in the study, 37 in group I and 34 in group II. The mean age of Group I was 23.7 ± 3.21 years, while the mean age of Group II was 71.58 ± 4.3 years. When the Group I and Group II groups were compared in terms of gender distribution, no significant difference was determined (p=0.718) (Table 1).

Table 1. Demographic features of the groups

	Group I (18-30 Years)	Group II (65-80 Years)	p
Age (years) Mean± SD	23.7 ± 3.21	71.58 ± 4.3	-
Gender (F/M)	19/18	16/18	0.718*

*Chi square test

The groups were then compared in terms of random saccade parameters. Latency was found to be significantly different, with Group 1 showing a shorter latency than Group II ($p<0.05$). Velocity and accuracy did not differ significantly between the two groups ($p=0.125$ and $p=0.370$, respectively) (Table 2).

Prosaccade and antisaccade parameters between groups differed significantly. When PS and AS parameters were evaluated, both PS and AS latency values were significantly shorter and both PS and AS error rates were significantly lower in the young group ($p<0.05$). Velocity and accuracy values did not differ significantly between the groups ($p=0.319$ and $p=0.392$ for PS and $p=0.589$ and $p=0.594$ for AS, respectively) (Table 3).

No significant difference was found between males and females in any parameters ((age ($p=0,707$); RS latency, velocity, accuracy ($p=0,606$, $p=0,699$, $p=0,251$, respectively); PS latency, velocity, accuracy ($p=0,679$, $p=0,963$, $p=0,992$, respectively); and AS latency, velocity, accuracy ($p=0,089$, $p=0,358$, $p=0,554$, respectively)).

Table 2. Comparison of random saccade parameters between the groups

	Group I (18-30 Years) (n:37)		Group II (65-80 Years) (n:34)		p
	(Mean±SD)	Range (Min-Max)	(Mean±SD)	Range (Min-Max)	
Latency (ms)	176.02±36.47	**125-238**	206.29±30.65	**157-248**	**0.000***
Velocity (°/s)	349.00±22.25	**269-377**	357.73±25.17	**306-420**	0.125
Accuracy (%)	95.24±4.7	**75-102**	96.17±3.86	**85-102**	0.370

SD: standard deviation, Significant at level:*: $p<0.05$

Table 3. Comparison of Prosaccade and Antisaccade parameters between the groups

	Group I (18-30 Years) (n:37)		Group II (65-80 Years) (n:34)		p
	(Mean±SD)	Range (Min-Max)	(Mean±SD)	Range (Min-Max)	
PS-Latency (ms)	226.89±45.83	160-349	270.79±60.24	182-457	**0.001**
PS-Velocity (°/s)	268.21±25.76	184-313	275.58±35.67	178-342	0.319
PS-Accuracy (%)	96.16±6.46	71-110	97.97±10.84	73-126	0.392
PS-Directional Error (%)	0.78±1.4	0-6	3.23±3.74	0-15	**0.000**
AS-Latency (ms)	325.56±49.33	242-424	383.73±80.10	181-508	**0.000**
AS-Velocity (°/s)	244.05±40.71	166-346	249.94±50.50	154-365	0.589
AS-Accuracy (%)	99.43±22.92	63-161	103.41±38.32	40-246	0.594
AS-Directional Error (%)	12.18±9.76	2-32	37.23±23.20	2-84	**0.000**

PS: Prosaccade, AS: Antisaccade, SD: standard deviation, Significant at level:*: $p<0.05$

DISCUSSION

In the study, the standard saccade latency, velocity, and accuracy along with PS and AS latency, velocity, accuracy, and DE parameter results of the saccadometry test were compared between healthy young and elderly adults. There is a study in the literature that compared the results between healthy participants aged between 18-69 years grouped according to age decades using the newly developed time-efficient saccadometry protocol (6). However, no study was encountered in the literature in which test results of both the random saccade and the new clinical saccadometry protocol were evaluated by taking a wider age range, especially in the elderly group. In this sense, the present study is unique in the literature.

Saccadic eye movements have been examined as biomarkers in Parkinson's and Huntington's Diseases, and it has been demonstrated that saccade latency is prolonged, velocity diminishes, and accuracy decreases with aging (13, 14). Abel et al. found that saccades were significantly slower in elderly individuals compared to young ones (15), and Munoz et al. demonstrated that age-related increases in the saccadic reaction period varied between 100-150 ms (12).

It has been reported that as a result of slowing in reflexes, receding in visual perception and motor performance, and decrease in fast movements along with aging, saccade functions can be affected due to prolonged reaction periods and latency (12, 16, 17). Yilmaz et al. found the saccade latency as 183.71±37.16 ms in the group aged between 65-82 years, while this value was determined as 124.25±22.58 ms in the group aged between 18-45 years (17).

Irving et al. reported that the saccade latency reached adult levels after age 14 and it was prolonged to 264 ms at age 80, following a course of increase after age 50 (18). Gedik et al. found significantly longer saccade latency in the group aged between 50-70 years compared to other age groups (19). Although the saccade latency period varied in studies, similar results were obtained, and a significant prolonging was observed in the latency period along with aging. In our study, similar to the literature, the saccade latency was found to be statistically significantly longer in the 65-80 age group (206.29±30.65) compared to the 18-30 age group (176.02±36.47), and the younger group showed a better performance. Tobener et al. concluded that the saccade latency differed with aging and that reaction times were prolonged, especially in childhood and old age periods, and they argued that these prolongations might have stemmed from age-related changes in cerebellar functions (20). Irving et al. stated that loss of cortical gray matter and decrease in neuronal density along with age could lead to prolongation in latencies (18).

In the literature, there is no consensus on whether saccadic velocity and accuracy change depending on age. Abel et al. could not determine a significant correlation between age and saccadic velocity (15). Gedik et al. determined that saccadic velocity and accuracy measurements did not differ between pediatric, young adult, and 50-70 age groups. They proposed that as the neural mechanisms responsible for saccadic accuracy mature at early ages, accuracy may not be affected by age (19). Spooner et al. found lower saccadic velocity in elderly individuals 65 years old and above compared to the younger group (21). In the study by Irving et al., saccadic velocity and accuracy especially in large saccades decreased along with age, and the researchers associated this situation with age-related neurological changes in the brain stem and cortical functions and the decrease in the mechanical efficiency of eye muscles (18). Similar to our study, Hopf et al. found no effect of age on saccade velocity and accuracy. They suggested that both parameters are resistant to the effects of normal aging and remain constant throughout life

(1). Moreover, this inconsistency in the literature may reflect methodological differences, age ranges of the sample groups, and individual characteristics.

In our study, AS and PS velocity and accuracy values did not differ between groups. Similar results were obtained in the study by Mack et al (22). They suggested that the basic function of the saccadic system, directing the eyes towards the next fixation target, is preserved throughout life and that this does not change saccade accuracy with age. They also stated that the reason why saccade velocity does not change is because the burst neurons in the saccade generator in the brainstem are resistant to aging.

PS and AS latencies of the younger group were found to be earlier compared to the elderly group in the saccadometry test in our study. In addition, intragroup AS latencies of both groups were prolonged compared to PS latencies. In studies conducted in the literature, while AS and PS performances decreased with aging, the values obtained varied (6, 12, 23). In their study, Demian et al. reported that the differences obtained in studies may have resulted from the number of repetitions in the saccadic movements, sampling differences, movement degrees for the saccadic movements, and the instructions given during tests (6).

Especially the brain makes a greater effort in AS formation compared to PS formation, and in the AS formation stage, procedures such as covertly orienting attention to the visual stimulus, inhibiting the prosaccade, and rematching the coordinates of the stimulus with the new position in the counter visual area should be performed (24). Connolly et al. examined the brain function during AS and PS tasks through functional magnetic resonance imaging (fMRI) and determined that the AS test activated especially the parietal and frontal regions more compared to the PS test and that during AS, the brain activated regions related to covert orienting, response inhibition, and coordinate transformation more. Therefore, it is believed that the earlier achievement of the PS latency compared to the AS latency may have resulted from the fact that executive functions and inhibition processes in the AS task require a higher cognitive burden (24). Thus, Demian et al. emphasized that it is important to use both tests together and that the cognitively more demanding AS and automatic PS reflected the integrity of the executive function (6).

In our study, PS and AS DE rates were found to be significantly lower in the younger group compared to the elderly group. On the other hand, the AS DE rate was found to be higher compared to the PS DE rate in both groups, and AS velocity was lower compared to PS velocity. It has been proposed that the decrease in AS performance can be associated with functional and structural changes in fields such as frontal eye fields (FEF), supplementary eye fields (SEF), dorsolateral prefrontal cortex (DLPFC), and superior colliculus (SC) (9). Mirsky et al. compared accurate AS response percentages in healthy elderly participants with neuropsychological test performance and gray matter volume measured through MRI. Even when the demographic variables such as age, gender, and education were controlled, they found that accurate AS response percentages were associated with executive functions. They determined that the accurate AS performance was associated with the gray matter volume of inhibitory control networks in the frontal lobe (specifically the right Supplementary Eye Field [SEF] and left Inferior Frontal Junction [IFJ]) (25). Structural differences in these regions have been considered important biological markers that may reflect deterioration in AS performance in normal aging or neurodegenerative processes (25). Wilcockson et al. found that with the AS task paradigm, the error rate increased in patients with mild cognitive impairment compared to normal people. They emphasized that mild cognitive disorders could be overlooked with traditional cognitive evaluations, and therefore eye tracking paradigms such as AS task could detect these disorders that may cause dementia in the

future and provide support as an early diagnostic marker (26). Even though our study focused healthy older participants, the results regarding saccadic performance could be the starting point for further studies into the potential of saccadometry as a precursor to cognitive decline. However, based on the available data, no definitive conclusions about cognitive disorders can be made.

In our study, no significant difference was found in AS and PS parameters in terms of genders. In their study, Demian et al. obtained similar results except for gender and velocity. They found that females had higher DE rates and longer latency in the AS test (6). Mack et al. found AS reaction time to be shorter in men than in women. They found no significant difference between the genders in terms of accuracy and error rates (22). Bonnet et al., similar to our study, found no difference between the genders (27). Inconsistencies in the literature regarding gender differences may be due to factors such as methodological differences and task design, sample size, and participant demographics. Mack et al. underlined the need of reporting the gender distribution in studies on eye movements even if the outcomes in the literature can differ. This makes it possible to compare the results of different studies in a more precise and thorough manner (22).

LIMITATIONS

In our study, participants up to the age of 80 years were included in the elderly group. However, since individuals of more advanced age were not evaluated, differences between sub-age groups within the elderly population could not be thoroughly examined. Future studies that will include older participants may more comprehensively elucidate the impact of aging not only on oculomotor functions but also on cognitive functions. In our study, a total of 60 jumps (151 ms) were performed for each PS and AS test. Increasing the number of jumps may result in more errors in the elderly group, especially in the directional error rate (DE) parameter. In future studies, it would be useful to evaluate the effect of increasing the number of jumps on saccadic parameters in a larger sample group. Finally, in our study, cognitive functions were evaluated with MMSE scores, but education levels were not compared. It is recommended that the effect of education level on saccadic parameters be evaluated in future studies. Moreover, more comprehensive neuropsychological evaluations were not included, which could be a focus of future research.

CONCLUSION

There is no study in the literature that comprehensively evaluates the results obtained with both the classical random saccade test and the new clinical saccadicometry protocol, especially in the elderly group, covering a wide age range (65-80 years). In this context, our study may contribute to the literature not only by deeply examining the effects of aging on the oculomotor system but also by revealing the clinical validity and potential application areas of the new saccadometry protocol in older age groups.

Our results suggest that age-related changes affect certain oculomotor functions, but some parameters remain consistent across healthy aging populations. Although our results contribute to normative data on saccadic performance in aging, they do not directly assess cognitive decline and neurodegenerative problems. Although our study focused on healthy individuals, our results may guide future research, including studies on neurodegenerative diseases, to evaluate the potential clinical value of oculomotor parameters.

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REFERENCES

1. Hopf S, Liesenfeld M, Schmidtmann I, Ashayer S, Pitz S. Age dependent normative data of vertical and horizontal reflexive saccades. PLoS One. 2018 Sep;13(9):e0204008. doi: 10.1371/journal.pone.0204008.
2. Kang JJ, Lee SU, Kim JM, Oh SY. Recording and interpretation of ocular movements: saccades, smooth pursuit, and optokinetic nystagmus. Ann Clin Neurophysiol. 2023 Oct;25(2):55–65. doi:10.14253/acn.2023.25.2.55
3. Sinno S, Najem F, Abouchacra KS, Perrin P, Dumas G. Normative values of saccades and smooth pursuit in children aged 5 to 17 years. J Am Acad Audiol. 2020 Jun;31(6):384-392. doi: 10.3766/jaaa.19049.
4. Antoniades CA, FitzGerald JJ. Using saccadometry with deep brain stimulation to study normal and pathological brain function. J Vis Exp. 2016 Jul;14(113):53640. doi: 10.3791/53640.
5. Rubino C, Andrushko JW, Rinat S, Harrison AT, Boyd LA. Oculomotor functional connectivity associated with motor sequence learning. Cereb Cortex. 2024 Nov;34(11):bhae434. doi: 10.1093/cercor/bhae434.
6. Demian D, Petrak M, Zielinski G et al. Clinical saccadometry: establishing evaluative standards using a simplified video oculography protocol in the adult population. J Am Acad Audiol. 2023 Feb;34(1-02):19-27. doi: 10.1055/s-0043-1772582.
7. Pretegiani E, Optican LM. Eye movements in parkinson's disease and inherited parkinsonian syndromes. Front Neurol. 2017 Nov;8:592. doi: 10.3389/fneur.2017.00592.
8. Kahana Levy N, Lavidor M, Vakil E. Prosaccade and antisaccade paradigms in persons with alzheimer's disease: a meta-analytic review. Neuropsychol Rev. 2018 Mar;28(1):16-31. doi: 10.1007/s11065-017-9362-4.
9. Munoz DP, Everling S. Look away: the anti-saccade task and the voluntary control of eye movement. Nat Rev Neurosci. 2004 Mar;5(3):218-28. doi: 10.1038/nrn1345.
10. Coe BC, Munoz DP. Mechanisms of saccade suppression revealed in the anti-saccade task. Philos Trans R Soc Lond B Biol Sci. 2017 Apr;372(1718):20160192. doi: 10.1098/rstb.2016.0192.
11. Yep R, Smorenburg ML, Riek HC et al. Interleaved pro/anti-saccade behavior across the lifespan. Front Aging Neurosci. 2022 May;14:842549. doi: 10.3389/fnagi.2022.842549.
12. Munoz DP, Broughton JR, Goldring JE, Armstrong IT. Age-related performance of human subjects on saccadic eye movement tasks. Exp Brain Res. 1998 Aug;121(4):391-400. doi: 10.1007/s002210050473.
13. Antoniades CA, Xu Z, Mason SL, Carpenter RH, Barker RA. Huntington's disease: changes in saccades and hand-tapping over 3 years. J Neurol. 2010 Nov;257(11):1890-8. doi: 10.1007/s00415-010-5632-2.
14. Antoniades CA, Demeyere N, Kennard C, Humphreys GW, Hu MT. Antisaccades and executive dysfunction in early drug-naive Parkinson's disease: The discovery study. Mov Disord. 2015 May;30(6):843-7. doi: 10.1002/mds.26134.
15. Abel LA, Troost BT, Dell'Osso LF. The effects of age on normal saccadic characteristics and their variability. Vision Res. 1983;23(1):33-7. doi: 10.1016/0042-6989(83)90038-x.
16. Seidler-Dobrin RD, Stelmach GE. Persistence in visual feedback control by the elderly. Exp Brain Res. 1998 Apr;119(4):467-74. doi: 10.1007/s002210050362.
17. Yilmaz N, Soylemez E, Ila K, Soylemez T, Ertugrul S. The effect of aging on oculomotor functions. J Ear Nose Throat Head Neck Surg. 2020;28(1):16-21. doi: 10.24179/kbbbbc.2019-72290.
18. Irving EL, Lillakas L. Difference between vertical and horizontal saccades across the human lifespan. Exp Eye Res. 2019 Jun;183:38-45. doi: 10.1016/j.exer.2018.08.020.
19. Gedik Ö, Bal N, Özdemir S, Akbey Seyrek Z, Çapar A. Comparison of videonystagmography findings in individuals of different age groups. KBB-Forum. 2021;20(1):15-22.
20. Tobener E, Searer A, Doettl S, Plyler P. Oculomotor findings in videonystagmography across the lifespan. J Am Acad Audiol. 2023 Feb;34(1-02):11-18. doi: 10.1055/s-0042-1760437.
21. Spooner JW, Sakala SM, Baloh RW. Effect of aging on eye tracking. Arch Neurol. 1980 Sep;37(9):575-6. doi: 10.1001/archneur.1980.00500580071012.
22. Mack DJ, Heinzel S, Pilotto A et al. The effect of age and gender on anti-saccade performance: Results from a large cohort of healthy aging individuals. Eur J Neurosci. 2020 Nov;52(9):4165-4184. doi: 10.1111/ejn.14878.

23. Klein C, Foerster F, Hartnegg K, Fischer B. Lifespan development of pro- and anti-saccades: multiple regression models for point estimates. Brain Res Dev Brain Res. 2005;160(02):113–123.

24. Connolly JD, Goodale MA, DeSouza JF, Menon RS, Vilis T. A comparison of frontoparietal fMRI activation during anti-saccades and anti-pointing. J Neurophysiol. 2000;84(03):1645–1655.

25. Mirsky JB, Heuer HW, Jafari A et al. Anti-saccade performance predicts executive function and brain structure in normal elders. Cogn Behav Neurol. 2011 Jun;24(2):50-8. doi: 10.1097/WNN.0b013e318223f6c6.

26. Wilcockson TDW, Mardanbegi D, Xia B et al. Abnormalities of saccadic eye movements in dementia due to Alzheimer's disease and mild cognitive impairment. Aging. 2019 Aug;11(15):5389-5398. doi: 10.18632/aging.102118.

27. Bonnet C, Hanuška J, Rusz J et al. Horizontal and vertical eye movement metrics: what is important? Clin Neurophysiol. 2013 Nov;124(11):2216-29. doi: 10.1016/j.clinph.2013.05.002.