

SMOOTH PURSUIT, SACCADDES, AND OPTOKINETIC NYSTAGMUS IN HEALTHY ADULTS: BINOCULAR VIDEONYSTAGMOGRAPHIC ANALYSIS

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ABSTRACT

Background: Objective assessment of oculomotor function provides valuable information for the evaluation of central and peripheral nervous system integrity. Videonystagmography (VNG) allows quantitative analysis of eye movements and facilitates the establishment of normative reference values in healthy populations. **Methods:** Oculomotor function was assessed in 31 healthy adults (mean age: 53.6 years, range: 19–79 years) with no history of neurological disease using videonystagmography. Optokinetic nystagmus, saccadic eye movements, and smooth pursuit eye movements were recorded. Participants were divided into two age groups (<50 and ≥50 years) to investigate age-related effects. Parameters analysed included gain, latency, velocity, accuracy, and peak velocity (velocity/amplitude ratio), depending on the type of eye movement. **Results:** Optokinetic nystagmus gain showed symmetrical responses between movement directions and decreased significantly with increasing stimulus velocity, while no significant association with age was observed. Saccadic eye movements demonstrated symmetrical performance in both horizontal and vertical planes. Saccadic latency increased significantly with age, whereas mean velocity, peak velocity, and accuracy were not significantly affected. Smooth pursuit gain decreased with increasing target motion frequency and age, particularly at higher frequencies, with horizontal smooth pursuit exhibiting higher gain values than vertical pursuit. **Conclusions:** The present study provides normative reference data for oculomotor parameters in a healthy Greek cohort. The findings also indicate that age-related effects on oculomotor function are parameter-specific, predominantly affecting timing-related and dynamic performance measures, while basic execution-related parameters remain relatively preserved. Ultimately, the data highlight the utility of modern binocular videonystagmography in precisely assessing oculomotor function, aiding in the differentiation between physiological aging and pathological conditions.

Keywords: saccades, smooth pursuit, optokinetic nystagmus

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Περίληψη

Εισαγωγή: Η αντικειμενική αξιολόγηση της οφθαλμοκινητικότητας παρέχει σημαντικές πληροφορίες για την εκτίμηση της ακεραιότητας τόσο του κεντρικού όσο και του περιφερικού νευρικού συστήματος. Η βιντεονυσταγμογραφία (VNG) επιτρέπει την καταγραφή και ανάλυση των οφθαλμικών κινήσεων διευκολύνοντας τον προσδιορισμό φυσιολογικών τιμών αναφοράς στον υγιή πληθυσμό. **Μεθοδολογία:** Μελετήθηκαν οι οφθαλμικές κινήσεις 31 υγιών ενηλίκων (μέση ηλικία: 53,6 έτη, εύρος: 19–79 έτη) με ελεύθερο ιστορικό νευρολογικής νόσου, με τη χρήση βιντεονυσταγμογραφικού συστήματος. Συγκεκριμένα καταγράφηκαν ο οπτοκινητικός νυσταγμός, οι σακκαδικές κινήσεις και η λεία κίνηση παρακολούθησης. Οι συμμετέχοντες χωρίστηκαν σε δύο ηλικιακές ομάδες (<50 και ≥50 ετών) για τη διερεύνηση της επίδρασης της ηλικίας. Οι παράμετροι που αναλύθηκαν περιλάμβαναν το gain, τη λανθάνουσα περίοδο, τη μέση και τη μέγιστη ταχύτητα,

καθώς και την ακρίβεια, αναλόγως του είδους της οφθαλμικής κίνησης. **Αποτελέσματα:** Ο οπτοκινητικός νυσταγμός παρουσίασε συμμετρική απόκριση μεταξύ των κατευθύνσεων κίνησης και μείωση του gain με την αύξηση της ταχύτητας του ερεθίσματος, χωρίς στατιστικά σημαντική συσχέτιση με την ηλικία. Οι σακκαδικές κινήσεις εμφάνισαν συμμετρική συμπεριφορά στο οριζόντιο και στο κάθετο επίπεδο, ενώ η λανθάνουσα περίοδος παρουσίαζε αύξηση με την αύξηση της ηλικίας. Αντίθετα, η μέση και η μέγιστη ταχύτητα, καθώς και η ακρίβεια, δεν επηρεάστηκαν σημαντικά από την ηλικία. Στις λείες κινήσεις παρακολούθησης παρατηρήθηκε μείωση του gain με την αύξηση της συχνότητας κίνησης του στόχου και της ηλικίας, κυρίως στο οριζόντιο επίπεδο. **Συμπεράσματα/συζήτηση:** Τα αποτελέσματα της μελέτης δείχνουν ότι οι ηλικιακές επιδράσεις στην οφθαλμοκινητικότητα είναι εξαρτώμενες από το είδος της παραμέτρου και του συστήματος ελέγχου, επηρεάζοντας κυρίως χρονικές και δυναμικές παραμέτρους, ενώ οι βασικοί μηχανισμοί εκτέλεσης των κινήσεων διατηρούνται. Η παρούσα εργασία παρέχει φυσιολογικές τιμές αναφοράς για παραμέτρους οφθαλμοκινητικότητας σε υγιή ενήλικο πληθυσμό και υποστηρίζει τη χρησιμότητα της βιντεονυσταγμογραφίας στην κλινική αξιολόγηση και στη διάκριση μεταξύ φυσιολογικής γήρανσης και παθολογικών καταστάσεων.

Λέξεις-κλειδιά: Σακκαδικές κινήσεις, λεία κίνηση παρακολούθησης, οπτοκινητικός νυσταγμός

INTRODUCTION

Oculomotor function is fundamental for maintaining clear, stable, and high-resolution vision, allowing accurate projection of a visual target onto the macula and, more specifically, the fovea. The transfer and stabilisation of the retinal image at the desired location are achieved through specialised eye movements, which are controlled by complex cortical, subcortical, cerebellar, and brainstem neural networks. In humans, eye movements are predominantly binocular and conjugate, with the visual axes of both eyes moving in the same direction^[1]. Different types of eye movements are subserved by distinct neural circuits within the central nervous system, all of which converge on a common final pathway downstream of the three ocular motor nuclei to innervate the extraocular muscles. The detailed functional neuroanatomy of these circuits has been extensively elucidated over recent decades, providing an excellent tool for the clinical neurologist in diagnostic practice. The present study focuses on three major types of conjugate eye movements: saccades, smooth pursuit, and optokinetic nystagmus, which constitute key indicators of the functional integrity of the oculomotor system.

Saccadic eye movements are rapid, brief eye movements that shift the visual axis from one target to another within the visual field. They represent the fastest voluntary movements of the human body and are characterised by high velocities, short duration, and a distinct latency period.^[1,3] The principal central nervous system structures involved in the execution of saccadic eye movements include^[2,3]:

- Frontal Eye Fields (FEF) and other structures of the cortex
- Dorsal vermis and the fastigial nucleus of the cerebellum
- Paramedian Pontine Reticular Formation, nucleus Prepositus Hypoglossi, and Medial Ves-

tibular Nucleus, for the horizontal saccades in the pons

- rostral interstitial nucleus of the Median Longitudinal Fasciculus, and Interstitial nucleus of Cajal for the vertical saccades in the midbrain.

Their evaluation is based on specific parameters^[4]:

- 1) latency: the time required for sensory processing and motor planning, until the initiation of motion.
- 2) mean and peak velocity: in degrees/sec. Considering that saccadic eye movement velocity is varying, both mean and peak velocity are employed for its assessment.
- 3) accuracy, defined as the degree of correspondence between the final eye position and the target location.

Smooth pursuit eye movements enable continuous tracking of slowly moving targets, maintaining the retinal image on the fovea throughout motion. Unlike saccades, smooth pursuit is characterised by continuous and smooth changes in eye position. The principal central nervous system structures involved in the execution of smooth pursuit movements include^[5]:

- Mainly parts of the visual cortex
- Floculus and parafloculus in the cerebellum
- the Dorsolateral Pontine Nuclei and the Medial Vestibular Nuclei.

The primary parameter used to assess smooth pursuit function is gain, defined as the ratio of eye velocity to target velocity, which ideally approaches unity.^[5]

Optokinetic nystagmus is a physiological reflex elicited by large-field visual motion stimuli that create the perception of environmental movement. It consists of an alternating slow phase, during which the eyes follow the moving visual pattern, and a fast resetting phase in the opposite direction.^[6] The main brain structures involved in optokinetic nystagmus are:

- The Nucleus of the Optic Tract
- The vestibular nuclei in the pons
- The flocculus in the cerebellum.

Analysis of the slow phase, commonly expressed by the gain parameter, is widely used to assess the functional interaction between visual and vestibular mechanisms.^[6]

Videonystagmography (VNG) has become an established, non-invasive method for recording and quantitatively analysing eye movements. Modern VNG systems allow precise measurement of multiple oculomotor parameters, like those that were mentioned before, and facilitate the development of normative databases, which are essential for the interpretation of pathological findings.

The aim of the present study is to quantitatively analyse saccadic eye movements, smooth pursuit, and optokinetic nystagmus in a healthy adult population using videonystagmography, as well as to investigate the effects of age and movement direction on selected parameters. The results of this study are intended to contribute to the establishment of reliable normative reference values for future comparisons with non-healthy populations.

MATERIALS AND METHODS

The present study was approved by the Ethics and Research Committee of Eginition Hospital.

Participants

Thirty-one healthy adults participated in the study, with no history of central nervous system disorders or other conditions that could affect oculomotor function. The sample included 16 females and 15 males, aged between 19 and 79 years. For the analysis of age-related effects, participants were divided into two age groups: younger than 50 years and 50 years or older.

Equipment

Eye movement recordings were obtained using the VisualEyes™ 525b videonystagmography system (Interacoustics, Denmark), which is based on videonystagmography (VNG) technology. Specialised goggles equipped with integrated infrared cameras were used to continuously record eye position and movement. Data were recorded, processed, and stored using the manufacturer's dedicated software. For selected analyses of saccadic eye movements, data were exported in ASCII format and analysed offline using custom-written laboratory software in MATLAB R2021b (MathWorks, Natick, MA, USA). Eye velocity was computed by digitally differentiating the displacement signal while accounting for the sampling rate of 100 Hz. The resulting time series was then smoothed using a tenth-order Butterworth low-pass filter with a cutoff frequency of 40 Hz, followed by

an eight-sample, first-order Savitzky–Golay filter.

Experimental procedure

Participants were examined in a seated position while wearing the VNG goggles and were instructed to visually follow stimuli presented on a screen positioned directly in front of them (**Figure 1**). All tests were performed according to standardised protocols and included recordings of saccadic eye movements, smooth pursuit eye movements, and optokinetic nystagmus.



Figure 1. Experimental setup for videonystagmographic recording of eye movements. Participants were seated facing the recording screen while wearing VNG goggles (here, facing a moving visual pattern for optokinetic nystagmus examination).

Saccadic eye movements

Saccadic eye movements were recorded in both the horizontal and the vertical plane. Participants were instructed to shift their gaze between sequential visual targets appearing at predefined positions on the screen.

The following parameters were analysed:

- Mean latency (ms)
- Mean velocity (°/s)
- Accuracy (%)
- Peak velocity, estimated using the velocity/amplitude (vel/amp) ratio, defined as the ratio of peak velocity to saccade amplitude.

Analyses were performed separately for each movement direction (rightward/leftward and upward/downward).

Smooth pursuit eye movements

Smooth pursuit eye movements were recorded in both the horizontal and the vertical plane. Participants were instructed to follow a visual target moving in a sinusoidal pattern at predefined frequencies.

The analysed parameters were:

- Gain, defined as the ratio of eye velocity to target velocity

- Symmetry, calculated from the difference in gain values between opposite movement directions and expressed as a percentage.

In the horizontal plane, five target motion frequencies were examined (0.1, 0.2, 0.3, 0.4, and 0.5 Hz), whereas in the vertical plane three frequencies were analysed (0.1, 0.2, and 0.3 Hz). Vertical smooth pursuit analysis was performed in 30 participants.

Optokinetic nystagmus

Optokinetic nystagmus was recorded in the horizontal plane. Participants were exposed to moving visual patterns covering a large portion of the visual field.

The analysed parameter was:

- Gain, defined as the ratio of the mean eye velocity during the slow phase of optokinetic nystagmus to the velocity of the moving visual stimulus

Recordings were performed at two different stimulus velocities.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics (version 21.0). Data are presented as mean $\pm$ standard deviation. The choice of statistical tests was based on the distribution of the variables. Normal reference ranges were determined using either ± 2 SD from the mean or the 5th–95th percentile range, depending on data distribution. Statistical significance was set at $p < 0.05$.

RESULTS

Participant characteristics

A total of 31 adults with no history of neurological disease were included in the study. Of these, 16 were female (51.6%) and 15 were male (48.4%). Participants' age ranged from 19 to 79 years, with a mean age of 53.6 years (SD: 17.9). Thirteen participants (41.9%) belonged to the younger age group (<50 years), while 18 participants (58.1%) were aged 50 years or older.

Optokinetic nystagmus

For optokinetic nystagmus, the gain of the slow phase was analysed in the horizontal plane at two stimulus velocities (20°/s and 40°/s) and for both directions. Mean gain values and standard deviations for the total sample, as well as for the two age groups (<50 and ≥ 50 years), were calculated and the proposed normal reference ranges for gain, based on data distribution, are shown in **Table 1**.

Comparison of mean gain values between the two movement directions (leftward vs. rightward) revealed no statistically significant differences at either

20°/s ($p = 0.40$) or 40°/s ($p = 0.78$). In contrast, comparison between stimulus velocities demonstrated significantly lower gain values at the higher velocity (40°/s) compared with 20°/s for both directions ($p < 0.001$). Correlation analysis between age and gain showed a negative association across all recording conditions; however, none of the correlations reached statistical significance ($p > 0.05$).

Table 1. Normal ranges of gain.

	Gain (20°/s) left-ward	Gain (40°/s) left-ward	Gain (20°/s) right-ward	Gain (40°/s) right-ward
Total sample (n=31)	60-100	35-102	55-108	33-106
Age <50 (n=13)	61 - 100	34 - 108	56 - 112	39 - 112
Age ≥ 50 (n=15)	50-113	36-100	53-106	30-100

Gain: eye velocity to target velocity ratio.

Saccadic eye movements

Mean values and standard deviations for all parameters for the total sample, as well as for the two age groups (<50 and ≥ 50 years) were calculated and

Horizontal saccades

For horizontal saccadic eye movements, the parameters latency, mean velocity, peak velocity (estimated using the velocity/amplitude (vel/amp) ratio), and accuracy were analysed for both directional movements. the proposed normal reference ranges are shown in **Table 2**.

Comparison between the two movement directions (rightward vs. leftward) revealed no statistically significant differences for any of the examined parameters ($p > 0.05$). Comparison between age groups demonstrated significantly longer latency values in participants aged ≥ 50 years compared with those aged <50 years ($p < 0.05$). No statistically significant differences between age groups were observed for mean velocity, peak velocity (vel/amp), or accuracy ($p > 0.05$). Correlation analysis showed a significant positive association between age and saccadic latency ($p < 0.05$), whereas no statistically significant correlations were found between age and the remaining parameters.

Vertical saccades

For vertical saccadic eye movements, the same parameters (latency, mean velocity, peak velocity/

amplitude, and accuracy) were analysed for upward and downward movements. The normal reference ranges are shown in **Table 2**. In **Figure 2A**, the representation of saccades in a graph during the examination is shown.

Comparison between upward and downward saccades revealed no statistically significant differences for any of the examined parameters ($p > 0.05$). Com-

parison between age groups showed significantly increased latency values for vertical saccades in participants aged ≥ 50 years compared with those aged < 50 years ($p < 0.05$) (**Figure 2B**). No statistically significant differences between age groups were observed for mean velocity, peak velocity, or accuracy.

Table 2. Normal ranges.

	Lat leftward (ms)	Lat rightward (ms)	Vel Leftward (°/s)	Vel rightward (°/s)	Ac. leftward (%)	Ac. rightward (%)	Vel/amp horizontal
Total sample (n=31)	153-260	188-239	305-409	274-432	79	77	23-41
Age <50 (n=13)	155 – 230	165 – 232	300-445	282-412	77	75	23-42
Age ≥ 50 (n=18)	163-271	190-255	270-449	268-445	82	78	23-40
	Lat downward (ms)	Lat upward (ms)	Vel downward (°/s)	Vel upward (°/s)	Ac. downward (%)	Ac. upward (%)	Vel/amp vertical
Total sample (n=31)	159-273	163-266	189-393	192-372	68	63	23-42
Age <50 (n=13)	149-260	160-240	187-400	204-365	70	77	23-42
Age ≥ 50 (n=18)	171-278	176-275	188-390	182-380	69	59	21-44

Lat: latency; vel: mean velocity; ac: accuracy; Vel/amp: peak velocity to saccade amplitude. For the accuracy variable, only the lower limit of the normal range is reported.

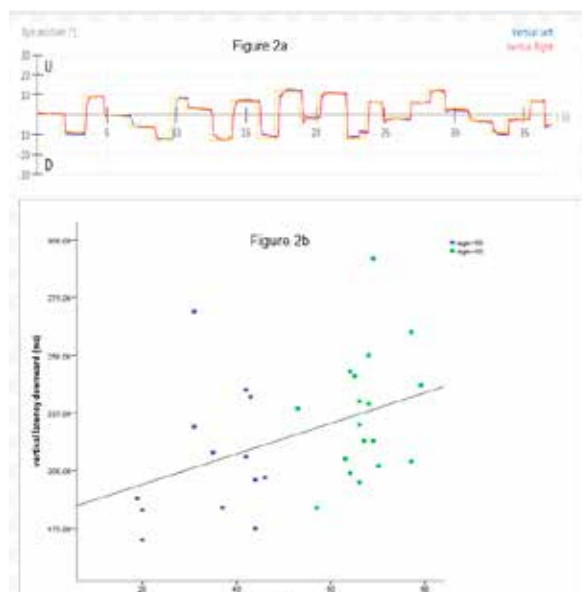


Figure 2. (A) Diagram illustrating saccadic movements on the vertical plane. On the x axis (t) is time, and on the y axis is the amplitude (position) of the movement. The yellow line represents the movement of the visual stimulus, while the blue and red lines represent the movements of the left and right eye, respectively. (B) Association between age (x-axis, years) and saccadic latency (y-axis, ms) for vertical, downward, and saccadic eye movements.

Smooth pursuit eye movements

Mean values and standard deviations for gain and symmetry for the total sample, as well as for the two age groups (< 50 and ≥ 50 years) were calculated for both horizontal and vertical plane of movement.

Horizontal smooth pursuit

For horizontal smooth pursuit eye movements, the parameters gain and symmetry were analysed at five target motion frequencies (0.1, 0.2, 0.3, 0.4, and 0.5 Hz). The proposed normal reference ranges are shown in **Tables 3** and **4**.

Comparison between the two movement directions (rightward vs. leftward) revealed no statistically significant differences for any of the examined frequencies ($p > 0.05$).

Comparison between age groups demonstrated

significantly lower gain values in participants aged ≥ 50 years compared with those aged < 50 years at the higher target motion frequencies (0.4 and 0.5 Hz; $p < 0.05$, Figure 3B). No statistically significant differences between age groups were observed at the lower frequencies (0.1–0.3 Hz; $p > 0.05$). For the symmetry parameter, no statistically significant differences were found either between movement directions or between age groups at any of the examined frequencies ($p > 0.05$).

Vertical smooth pursuit

For vertical smooth pursuit eye movements, the

($p > 0.05$).

same parameters (gain and symmetry) were analysed at three target motion frequencies (0.1, 0.2, and 0.3 Hz). In **Figure 3A**, there is a graph depiction of smooth pursuit movement on the vertical plane during the recording. The normal reference ranges are shown in **Tables 3** and **4**.

Comparison between upward and downward movements revealed no statistically significant differences in gain or symmetry at any of the examined frequencies ($p > 0.05$). Comparison between age groups did not reveal any statistically significant differences in gain or symmetry values for vertical smooth pursuit at any of the examined frequencies

Table 3. Normal values for gain in the horizontal and vertical plane.

	Gain left-ward 0.1Hz	Gain rightward 0.1Hz	Gain left-ward 0.2Hz	Gain rightward 0.2Hz	Gain left-ward 0.3Hz	Gain rightward 0.3Hz	Gain left-ward 0.4Hz	Gain rightward 0.4Hz	Gain left-ward 0.5Hz	Gain rightward 0.5Hz
Total sample (n=31)	50-102	61-106	54-105	52-118	42-103	40-107	42-113	33-122	35-105	30-123
Age<50 (n=13)	62-101	80-110	66-103	60-108	70-112	72-118	65-108	61-112	45-104	47-121
Age$\geq$50 (n=18)	47-117	42-119	46-116	50-110	34-118	30-123	33-110	22-123	20-113	19-119
	Gain upward 0.1Hz	Gain down-ward 0.1Hz	Gain up-ward 0.2Hz	Gain down-ward 0.2Hz	Gain up-ward 0.3Hz	Gain down-ward 0.3Hz				
Total sample (n=30)	74 $\pm$ 21	75 $\pm$ 22	81 $\pm$ 21	75 $\pm$ 21	78 $\pm$ 24	66 $\pm$ 25				
Age <50 (n=13)	78 $\pm$ 24	80 $\pm$ 22	80 $\pm$ 25	82 $\pm$ 22	82 $\pm$ 23	74 $\pm$ 24				
Age $\geq$50 (n=17)	71 $\pm$ 18	71 $\pm$ 22	82 $\pm$ 19	70 $\pm$ 22	74 $\pm$ 25	60 $\pm$ 25				

Gain: eye velocity to target velocity ratio.

Table 4. Normal values for symmetry in the horizontal and vertical plane.

	Symmetry 0.1Hz (hor) (%)	Symmetry 0.2Hz (hor) (%)	Symmetry (hor) 0.3Hz (%)	Symmetry (hor) 0.4Hz (%)	Symmetry (hor) 0.5Hz (%)	Symmetry 0.1Hz (ver) (%)	Symmetry 0.2Hz (ver) (%)	Symmetry 0.3Hz (ver) (%)
Total sample (n=31)	(-14)-11	(-6.5)-14	(-18)-18	(-24)-24	(-34)-51	1.5±14	(-4)±28	(-13)±30
Age<50 (n=13)	(-18)-3.8	(-7)-9	(-18)-13	(-17)-17	(-33)-31	2.3±13	6.7±27	(-7.8)±22
Age≥50 (n=18)	(-13)-17	(-11)-21	(-35)-35	(-29)-30	(-66)-68	1±15	-12±27	(-16)±32

Symmetry: (gain difference between directions / sum of gains)%; hor: horizontal; ver: vertical.

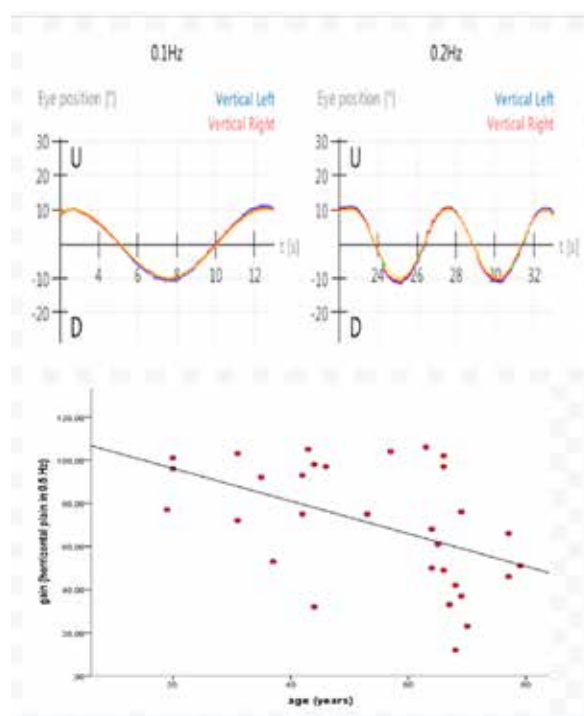


Figure 3. (A) Graph illustrating smooth pursuit movement on the vertical plane in two different frequencies of the moving target (0.1 Hz, 0.2 Hz). The x-axis corresponds to time, and the y-axis to the amplitude (position) of the movement (U=up, D=down). The yellow line corresponds to the visual stimulus, while the blue and red lines correspond to the left and right eye, respectively. As time progresses, the frequency of the movement also increases. **(B)** Inverse association between age (x-axis, in years) and smooth pursuit gain (y-axis) for horizontal smooth pursuit at a target motion frequency of 0.5 Hz.

DISCUSSION

Summary of the study

Modern neurophysiological techniques for recording

eye movements^[7,8] with unprecedented precision have gradually entered neurological practice and are yielding insights into a variety of diseases accompanied by peripheral^[9-13] or central^[14-21] eye movement disorders. Advances in methodology, together with the introduction of new hardware and analysis software, necessitate the continuous updating of normative values, as reliance on older data obtained with previous setups may be imprecise. The present study investigated oculomotor function in a healthy adult population using videonystagmography, focusing on optokinetic nystagmus, saccadic eye movements, and smooth pursuit eye movements. Overall, the results demonstrated symmetrical oculomotor performance and revealed age-related differences in selected parameters, highlighting the importance of considering age effects when interpreting oculomotor findings in healthy individuals.

Optokinetic nystagmus

In the present study, the analysis of optokinetic nystagmus focused on the slow phase of the response in the horizontal plane, using the gain parameter. The results demonstrated symmetrical responses between the two movement directions (leftward and rightward), a finding consistent with normal optokinetic system function. In contrast, a clear reduction in gain was observed with increasing stimulus velocity, a pattern that has been consistently reported in previous studies and is commonly attributed to limitations in optokinetic processing at higher velocities.

With regard to the effect of age, although participants younger than 50 years exhibited higher gain values across all recording conditions, these differences did not reach statistical significance. Similarly, correlation analysis revealed a tendency toward decreasing gain with increasing age, without achieving statistical

significance. These findings are in line with previous reports showing age-related reductions in optokinetic gain, although the age at which such reductions become evident varies considerably across studies.

Specifically, Ura et al.^[22] reported a significant reduction in gain when comparing age groups of 30 and 80 years, whereas Baloh et al.^[23] described reduced slow-phase velocities of optokinetic nystagmus in individuals aged 75 years and older. A potential limitation of the present study is the small number of participants older than 70 years, which may have limited the ability to detect statistically significant differences in the oldest age groups.

Saccadic eye movements

In the present study, saccadic eye movements were analysed by examining latency, mean velocity, accuracy, and peak velocity, the latter estimated using the velocity/amplitude (vel/amp) ratio, separately for horizontal and vertical saccades.

With respect to horizontal saccades, no statistically significant differences were observed between the two movement directions for any of the examined parameters. This finding is consistent with previous studies, in which directional asymmetries are not expected in healthy populations.^[24,25] Similar results have been reported in the literature, although some studies, such as that of Vergilino-Perez et al., have described higher peak velocities toward the dominant eye direction, without corresponding differences in saccadic latency.^[26]

Age emerged as a significant factor influencing horizontal saccadic latency, with increased latency values observed in older participants. This finding corroborates previous reports demonstrating a positive association between age and saccadic latency, commonly attributed to age-related changes in the neural mechanisms underlying saccade planning and initiation. In contrast, mean velocity and peak velocity were not significantly affected by age. This observation is in agreement with studies suggesting preservation of the core neural mechanisms responsible for saccade execution with advancing age,^[27-29] although the literature remains inconclusive regarding age-related changes in peak velocity.^[27,30]

A similar pattern was observed for vertical saccades. Saccadic latency increased significantly with age for both upward and downward movements, whereas mean and peak velocity did not show a clear age-related effect. These findings further support the notion that aging predominantly affects the initiation and planning stages of saccadic eye movements, irrespective of movement plane.

Smooth pursuit eye movements

In the analysis of smooth pursuit eye movements, the parameters gain and accuracy were examined

separately in the horizontal and vertical planes.

With regard to horizontal smooth pursuit, a progressive reduction in gain was observed with increasing target motion frequency, particularly at frequencies ≥ 0.3 Hz, accompanied by increased variability of the recorded values. No statistically significant differences were detected between the two movement directions (leftward and rightward), a finding consistent with the expected symmetrical functioning of the smooth pursuit system in healthy individuals. In contrast, age emerged as a significant factor affecting performance, with younger participants exhibiting higher gain values at medium and high frequencies. Similar age-related effects have been reported in previous studies, in which the impact of aging becomes more evident under conditions of increased pursuit demands.^[31,32]

For vertical smooth pursuit eye movements, the results were less homogeneous. Differences in gain between upward and downward movements were observed only under specific high-frequency conditions. This finding is in agreement with the existing literature, which reports inconsistent results regarding directional differences in vertical smooth pursuit. While some studies have found no differences between upward and downward movements,^[33] others have reported higher gain either for upward or for downward smooth pursuit.^[34,35]

In contrast to horizontal smooth pursuit, no clear association between age and gain was demonstrated for vertical smooth pursuit eye movements. The absence of statistically significant age-related effects may be related to the limited number of studies that have systematically investigated vertical smooth pursuit across different age groups, as well as to the greater complexity of the neural mechanisms involved in the control of vertical pursuit.

LIMITATIONS

The main limitation of the present study is the relatively small sample size, which may restrict the generalisability of the findings, particularly in older age groups. Nevertheless, the study provides an initial normative dataset in a healthy adult population, which can be further expanded through continuous data collection to improve representativeness.

In addition, increased variability was observed in certain parameters, such as saccadic accuracy and smooth pursuit gain at higher stimulus velocities. This variability may not be solely attributable to sample size but could also reflect factors related to participant compliance, including fatigue and reduced attention during testing. Such factors are particularly relevant in studies involving healthy individuals, in whom motivation and alertness may vary across testing sessions.

CLINICAL IMPLICATIONS AND CONCLUSIONS

The recording and analysis of eye movements using videonystagmography provide access to quantitative parameters, such as timing, velocity, and accuracy, which are often beyond the sensitivity of routine clinical observation. The present study contributes to the establishment of normative reference data for oculomotor parameters in a healthy adult population, offering a valuable baseline for the assessment of patients with suspected oculomotor dysfunction.

Furthermore, the ability to analyse oculomotor parameters in relation to demographic factors, such as age and sex, highlights the utility of videonystagmography in both clinical and research settings. Consequently, this method may support early detection of neurological disorders, including neurodegenerative diseases, in which oculomotor function may be impaired, as well as aid in the differential diagnosis between central and peripheral nervous system pathologies.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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