Adduction-Abduction Asymmetry in Saccades During Video-Oculographic Monocular Recording: A Word of Caution

Koji Takahashi^a, Osamu Tanaka^a, Yosuke Kudo^b, Eriko Sugawara^b, and Ken Johkura^{a,b}

^aDepartment of Clinical Laboratory, Yokohama Brain and Spine Center, Yokohama, Japan; ^bDepartment of Neurology, Yokohama Brain and Spine Center, Yokohama, Japan

ABSTRACT

In eye movement examination, video-oculographic monocular recording has become more popular than electro-oculographic binocular recording. The aim of this study was to examine the characteristics of monocular movements recorded using video-oculography. In 66 healthy subjects, the horizontal saccades and smooth pursuit eye movements of the right eye within a range of 30° were evaluated using a video-oculographic eye movement recording system. Saccade latency, velocity, accuracy, and smooth pursuit gain were measured and analysed by age and direction. Saccade parameters (latency, velocity, and amplitude) and smooth pursuit gain deteriorated with age in healthy subjects. Saccade velocity and accuracy were significantly larger during adduction than during abduction. The smooth pursuit gain did not differ between adduction and abduction. In conclusion, unlike smooth pursuit eye movements, saccadic eye movements have adduction-abduction asymmetry. In video-oculographic monocular recording of saccades, it is necessary to recognise the possibility of the existence of adduction-abduction asymmetry.

ARTICLE HISTORY

Received 25 September 2018
Revised 29 October 2018
Accepted 2 December 2018

KEYWORDS

Video-oculography;
monocular recording;
saccade; adduction;
abduction

Introduction

During the measurement of conjugate eye movements such as horizontal saccades and smooth pursuits using electro-oculography (EOG), movements of both eyes are recorded together using bilateral temporal electrodes placed at the lateral margin of the orbits. On the other hand, when using video-oculography (VOG), movements of either the right or left eye are recorded even during the measurement of conjugate eye movements. Recently, VOG has become more popular than EOG for the measurement of eye movements because it is an easier technique.¹ However, characteristics of monocular recording using VOG may differ from those of binocular recording using EOG. The aim of this study was to examine the characteristics of monocular movements recorded using VOG.

Material and methods

A total of 66 healthy volunteers (31 men and 35 women, aged 21–75 years [mean $\pm$

SD = 42.1 $\pm$ 14.6 years]) who had no history of neurological, ophthalmological, or otological disorder participated in this study. Right eye movements were measured while participants were in a supine position on a bed with the head fixed. A laser pointer projected onto the ceiling was used as the visual target for horizontal saccades and smooth pursuit eye movements.¹ For horizontal saccades, the laser pointer jumped randomly 15° either in the right or left direction from the mid position at random intervals. For horizontal smooth pursuits, the laser pointer moved according to a sine curve velocity profile with an amplitude of 30° and a frequency of 0.3Hz.¹ Participants were instructed to track the laser pointer.

Eye movements were recorded using a VOG-based recording system (IRN-2, J. Morita Mfg. Corp., Kyoto, Japan).^{1–4} Before testing with a visual target randomly appearing or moving, eye position was calibrated by fixing on a 15° right and 15° left target for 4s. Participants

were also instructed to confirm that the laser pointer on the ceiling was clearly visible during calibration. Eye and visual target positions were sampled 60 times per second, and velocities were calculated at each eye position.¹

In the 15° saccade evaluation, a saccade was defined as the first eye movement towards the target direction; the beginning of the saccade was defined when the velocity exceeded 1 standard deviation (SD) of all the sampling velocities of the eye movement, and the end of the saccade was defined when the velocity became equal to or lower than 1 SD. For saccade latency, maximum velocity, and accuracy (eye position when the saccade stopped/target position) were measured during a 180s period (approximately 20 trials for each direction of saccade).

In the smooth pursuit evaluation, smooth pursuit gain (eye velocity/laser pointer velocity) during a 30s period of laser pointer tracking was obtained from a linear regression formula derived from eye-velocity–target-velocity plotted on the least squares regression line automatically. A more detailed calculation method has been described elsewhere.¹

The relationship between age and each saccade and smooth pursuit parameter was analysed using the Pearson correlation coefficient. Differences based on the direction of the saccade and smooth pursuit parameters were analysed using the paired *t*-test. All statistical analyses were performed with the SPSS Statistical software (version 22, IBM, Armonk, NY), and $p < 0.05$ was considered statistically significant.

This study was approved by our institutional ethics committee, and informed consent was obtained from all participants.

Results

During the evaluation of eye movements in the right and left directions, the mean (SD) saccade latency, velocity, and accuracy were 217.6 (36.7) ms, 339.6 (48.8) °/sec, and 90.9 (9.9) %, respectively. The mean (SD) smooth pursuit gain was 0.88 (0.14). Each parameter was weakly correlated with age; the saccade latency ($r = 0.354$, $p < 0.001$) was prolonged, the saccade velocity ($r = -0.267$, $p = 0.002$) and accuracy ($r = -0.290$, $p = 0.001$) were reduced, and the smooth pursuit gain ($r = -0.391$, $p < 0.001$) was decreased with age in healthy subjects (Figure 1).

Figure 1. Relationship between age and each saccade and smooth pursuit parameter obtained from the right eye. Both right (abduction) and left (adduction) directional eye movements of each subject are plotted.

During saccades in the left direction (adduction), the mean (SD) latency, velocity, and accuracy were 210.7 (33.8) ms, 351.8 (49.7) °/sec, and 95.8 (9.3) %, respectively, whereas the values of these parameters were 224.6 (38.4) ms, 327.4 (45.1) °/sec, and 86.0 (7.8) %, respectively, for saccades in the right direction (abduction). Saccade latency was significantly shorter in the left direction (adduction) than in the right direction (abduction) ($p < 0.001$). Similarly, saccade velocity and accuracy were significantly larger in the left direction (adduction) than in the right direction (abduction) ($p < 0.001$ for velocity and $p < 0.001$ for accuracy) (Table 1). On the other hand, the mean (SD) smooth pursuit gain was 0.88 (0.14) % in the left direction (adduction) and 0.88 (0.13) % in the right direction (abduction). The smooth pursuit gain did not differ between adduction and abduction ($p = 0.919$) (Table 1). A shorter latency and a larger velocity and accuracy were observed for all ages during the adduction saccade (Figure 2).

Table 1. Directional differences in eye movements.

Eye movement	Adduction direction	Abduction direction	<i>p</i>
Saccade latency (ms)	210.7 (33.8)	224.6 (38.4)	<0.001
Saccade velocity (°/sec)	351.8 (49.7)	327.4 (45.1)	<0.001
Saccade accuracy (%)	95.8 (9.3)	86.0 (7.8)	<0.001
Smooth pursuit gain	0.88 (0.14)	0.88 (0.13)	0.919

Note. Data are shown as mean (SD).

Discussion

This study showed ‘normal values’ of visually guided 15° saccade latency, velocity, and accuracy, and sinusoidal smooth pursuit (amplitude of 30° and frequency of 0.3Hz) gain during VOG recording. These values were not largely contradictory to the reported normal values measured in different ways.^{5,6} Deteriorations with age in these values in our study are also consistent with previous reports.^{6,7} However, these values did not seem to be very important, because they depended on the characteristics of measuring equipment such as VOG sampling rate. The aim of this study was not to obtain the absolute normal values of saccade and smooth pursuit parameters in VOG recording but to investigate the characteristics of monocular recording using VOG.

During the measurement of right eye movements, there were significant directional differences only in the saccade parameters. The saccade latency was significantly shorter, and the saccade velocity and accuracy were significantly larger in the left (adduction) direction than in the right (abduction) direction. Additionally, the smooth pursuit gain did not differ between both directions. Because the left–right asymmetry may be due to characteristics of measuring with right eye, we additionally measured left eye

Figure 2. Changes in directional differences in eye movement parameters by age. Eye movements in the right (abduction) and left (adduction) directions are plotted separately. Mean $\pm$ SE is shown in the graph.

saccades and smooth pursuits in 10 healthy subjects (3 men and 7 women, aged 23–55 years [mean $\pm$ SD = 38.3 ± 12.1 years]), and confirmed that saccade velocity and accuracy were larger in the right (adduction) direction than in the left (abduction) direction (Supplement 1). Furthermore, in this study, the laser pointer (visual target) generator was placed just above the forehead (midline). It was slightly shifted from the centre of the measured eye, and thus, might have affected the measurement results. Therefore, we additionally measured left eye saccades and smooth pursuits with the position of the laser pointer (visual target) generator shifted from just above the forehead towards the lateral (left) direction in a healthy subject (23-year-old woman), and confirmed the adduction dominance of saccades (Supplement 2).

There have been many reports of adduction–abduction asymmetry of saccades in healthy subjects. However, there is no consensus on which direction of saccade is faster/larger. Miyoshi et al.⁸ reported that the saccades of the adducting eye had a higher velocity and overshoot tendency whereas the saccades of the abducting eye had a lower velocity and undershoot tendency in 10 healthy subjects. On the contrary, Collewijn et al.⁹ reported that the saccades of the abducting eye had a higher peak velocity and larger size than the concomitant adducting saccades of the fellow eye in three subjects. Träisk et al.¹⁰ reported no significant difference regarding peak velocity between the adducting and abducting saccades in 10 subjects. Our study showed a shorter latency, higher peak velocity, and larger accuracy of the adducting saccades. Faster and larger adduction saccades were also confirmed in the fellow eye (Supplement 1). Although the precise mechanism is unknown, saccade–vergence interaction may possibly be involved in the adduction–abduction asymmetry.^{11,12} It is difficult to conclude definitely that the adducting saccades are faster and larger from our measurement results, because we measured saccades and smooth pursuits using only one method, VOG with a relatively low sampling rate. The larger adduction saccades may be more likely than the faster adducting saccades because accuracy can be measured accurately even with low sampling rate VOG. Anyway, our study is clearly indicative that there is an adduction–abduction asymmetry in saccades, but not in smooth pursuits, in the widely used VOG monocular recordings.

Our study was limited by the small number of participants. Our VOG sampling rate was also quite low. When VOG is used, a higher sampling rate is required for accurate analysis of quick motions such as saccades. In order to confirm physiological adduction–abduction asymmetry of saccades, verification by other methods (such as magnetic scleral search coil oculography and EOG) is required. It is also necessary to investigate whether the adduction–abduction asymmetry is amplitude-dependent.

In conclusion, our study showed an adduction–abduction asymmetry in saccadic eye movements during VOG monocular measurement. In binocular recording using EOG, such asymmetry, if present, does not affect the measurement results. However, the adduction–abduction asymmetry may affect the measurement results in monocular recording using VOG. During the measurement of saccades using monocular VOG, especially when using VOG with specifications similar ours (standard specifications widely used clinically), it is necessary to recognise the possibility of the existence of adduction–abduction asymmetry.

Declaration of interest

The video-oculography-based recording system with the laser pointer projector was provided by J. Morita Mfg. Corp.

Funding

No funding was received for this work.

References

1. Johkura K, Kawabata Y, Amano Y, Kudo Y, Murata H, Kirimura S, Funabiki K. Bedside evaluation of smooth pursuit eye movements in acute sensory stroke patients. *J Neurol Sci.* 2015;348:269–271. doi:[10.1016/j.jns.2014.12.013](https://doi.org/10.1016/j.jns.2014.12.013).
2. Funabiki K, Naito Y, Matsuda K, Honjo I. A new vestibulo-ocular reflex recording system designed for routine vestibular clinical use. *Acta Otorinolaryngol.* 1999;119:413–419. doi:[10.1080/00016489950180928](https://doi.org/10.1080/00016489950180928).
3. Johkura K, Yoshida TN, Kudo Y, Nakae Y, Momoo T, Kuroiwa Y. Cilostazol versus aspirin therapy in patients with chronic dizziness after ischemic stroke. *Clin Neurol Neurosurg.* 2012;114:876–880. doi:[10.1016/j.clineuro.2012.01.029](https://doi.org/10.1016/j.clineuro.2012.01.029).
4. Murai N, Funabiki K, Naito Y, Ito J, Fukuyama H. Validity and limitation of manual rotational test to detect impaired

- visual-vestibular interaction due to cerebellar disorders. *Auris Nasus Larynx*. 2005;32:23–28. doi:10.1016/j.anl.2004.11.010.
5. Boghen D, Troost BT, Daroff RB, Dell'Osso LF, Birkett JE. Velocity characteristics of normal human saccades. *Invest Ophthalmol*. 1974;13:619–623.
 6. Leigh RJ, Zee DS. *The Neurology of Eye Movements*. 5th ed. New York, NY: Oxford University Press; 2015.
 7. Dowiasch S, Marx S, Einhäuser W, Bremmer F. Effects of aging on eye movements in the real world. *Front Hum Neurosci*. 2015;9:46. doi:10.3389/fnhum.2015.00046.
 8. Miyoshi T, Hiwatashi S, Kishimoto S, Tamada A. Dissociation of the eyes in saccadic movement. *Ann N Y Acad Sci*. 1981;374:731–743.
 9. Collewyn H, Erkelens CJ, Steinman RM. Binocular co-ordination of human vertical saccadic eye movements. *J Physiol*. 1988;404:183–197.
 10. Träisk F, Bolzani R, Ygge J. A comparison between the magnetic scleral search coil and infrared reflection methods for saccadic eye movement analysis. *Graefes Arch Clin Exp Ophthalmol*. 2005;243:791–797. doi:10.1007/s00417-005-1148-3.
 11. Zee DS, Fitzgibbon EJ, Optican LM. Saccade-vergence interactions in humans. *J Neurophysiol*. 1992;68:1624–1641. doi:10.1152/jn.1992.68.5.1624.
 12. Hung GK, Zhu H, Ciuffreda KJ. Convergence and divergence exhibit different response characteristics to symmetric stimuli. *Vision Res*. 1997;37:1197–1205.