The Influence of Horizontal Convergence on Slow Oscillatory Eye Movements During Visual Fixation

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Purpose. Slow oscillatory eye movements (SOMs) occur simultaneously with tremor, drifts, and microsaccades during visual fixation. In a previous study, the amplitude of SOM was found to be affected by the visual characteristics of the stimuli. This indicates a perceptual influence on the control of the movement. However, the frequency of SOM did not change. The aim of our study was to investigate how SOM is affected by extraocular muscle tension.

Methods. In a repeated-measurement experiment, 14 subjects were instructed to maintain fixation for 3 minutes on a bright dot presented at four distances (15, 30, 60, and 120 cm). The level of extraocular muscle tension is assumed to increase with decreased fixation distance due to convergence angle. Eye movements were recorded binocularly using a video eye tracker, and the amplitude and frequency of SOM for each eye were obtained by independently filtering the horizontal and vertical eye position signals with a discrete Fourier transformation.

Results. The results showed no significant differences for the amplitude. However, the horizontal frequency was found to be significantly lower at the closest distance. No significant differences were found for the vertical frequency.

Conclusions. Based on these findings we conclude that extraocular muscle tension does have an effect on the frequency, but not the amplitude, of the oscillations. The apparent double dissociation between perceptual effects on amplitude versus muscle tension effects on frequency is discussed in relation to the origin and control of SOM.

Keywords: eye movements, extraocular muscle, muscle force, ocular convergence

Slow oscillatory eye movements (SOMs) recently were shown to appear together with tremor, drifts, and microsaccades during visual fixation of a stationary target.[1] The SOM oscillates the line of sight around the fixation target for one period ranging from 10 to 25 seconds with amplitude ranging between 0.05° and 0.50°. The slow eye movements can be observed in recordings of visual fixation in some previous publications.[2–4] When Miller et al.[5] used a muscle tension transducer of their own design to measure rectus muscle tension, they found that the lateral (LR) and medial (MR) rectus tension signals showed small, apparently random, uncorrelated drifts. They suspected those slowly varying tensions were physiologic, because of the high stability of muscle tension transducers outside the body.

The SOM amplitude was shown to change depending on the spatial characteristics of the visual stimuli,[6] indicating a perceptual influence on the SOM control. A larger nonstructured target induced larger SOM amplitude compared to a smaller target. However, changing the visual parameters did not modify the SOM frequency. Even in complete darkness, the period of SOM remained constant despite a 20-fold increase of amplitude.

This raises the question of whether the SOM frequency is an inherent property for each individual, or whether it can be modified by variation in the level of motor input to the eye muscles during fixation. In our study, we have tested this idea by recording SOM during convergence of varying angle at four different fixation distances. Through the evaluation of the effect of the horizontal convergence, we tried to investigate if the extraocular muscle (EOM) tension has any influence on SOM, especially in frequency. The outcome is of importance to understand better the control of SOM, and is helpful to reveal the underlying etiology of the slow oscillatory eye movements.

Methods

Subjects

Our study enrolled 14 healthy individuals (4 male and 10 female; mean age, 38.1 years; age span, 20–65 years). None of the subjects had a history of neurologic or ophthalmologic disorder. Subjects did not take any medication of a possible influence on the central nervous system before the test. Each test subject had an ophthalmic examination, stereoscopic vision test (LANG, <200 sec arc), normal near point of convergence examination (<10 cm), and dominant eye determination at close distance. The nature and possible consequences of this study were explained before the test, and all individuals gave informed consents. This study adheres to the tenets of the Declaration of Helsinki (World Medical Association; Declaration of Helsinki/October 2008).

Recording Technique

Eye position of the right and left eyes was recorded (50 Hz) using the head-mounted video oculography system C-ETD (Chronos Vision GmbH, Berlin, Germany).

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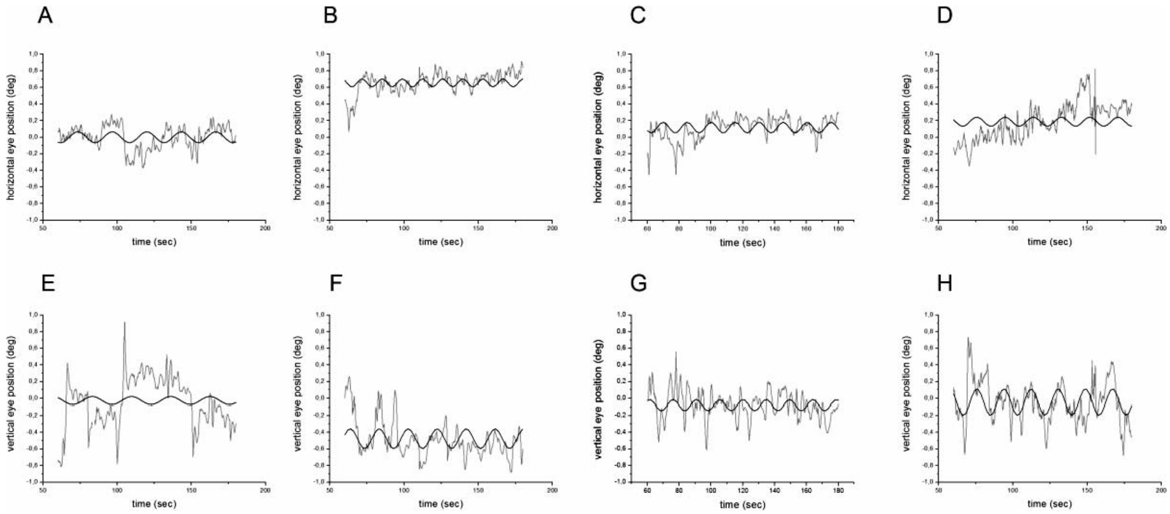

FIGURE 1. The figures present the recordings from one subject. The *upper row* (**A–D**) shows the horizontal eye position signal and the *lower row* (**E–H**) shows the vertical eye position signal. (**A**, **E**) correspond to cl 15. (**B**, **F**) correspond to cl 30. (**C**, **G**) correspond to cl 60. (**D**, **H**) correspond to cl 120. Sine fitting function (*black line*) revealed the slow oscillatory eye movements, which are superimposed on the smoothed eye position signals (*grey line*).

Visual Stimulus and Paradigms

The visual stimulus was a red dot positioned in the midline in front of the subject at level with the eyes. A small red lamp was built into a black box (7.5 × 8.5 × 9.5 cm) illuminating a hole (3 × 3 mm) with translucent adhesive tape on its front side, creating a sharp visible red dot. The distance between the eye and the red dot could be adjusted by moving the box. The investigation room was dark (0.2 cd/m^2) except for the light from the visual stimuli.

The subject was seated with a chin rest and a bite bar to minimize head movements. A binocular 9-point horizontal and vertical calibration (amplitude 4° and 8°) was conducted for each subject before the test sessions. The calibration procedure lasted for 20 seconds. Each subject performed four tests with four different target-eye distances (i.e., convergence levels [cl]); 15 cm (cl 15), 30 cm (cl 30), 60 cm (cl 60), and 120 cm (cl 120). The viewing condition always was binocular. Each test lasted for 3 minutes and there was a 5-minute interval between two successive recordings. The test subjects were randomized into one of two groups. The first group performed the four tests from far to near (cl 120, cl 60, cl 30, and cl 15), while the second group performed the four tests from near to far (cl 15, cl 30, cl 60, and cl 120).

Data Analysis and Statistics Methods

The data analysis performed was the same as described in our previous study.[6] Firstly, the eye position signals were calibrated and retrieved using the Offline Iris software (Chronos Vision GmbH). Then, a frequency analysis was performed separately on the vertical and horizontal eye position signals by the discrete Fourier transformation (DFT) using a Hamming window. The peak value in the DFT plot was used as the initial value in the sine fitting procedure to reveal a more precise frequency of SOM. The eye position track was fitted by the sine function:

$$y = y_0 + Asin\left(\pi\frac{t - t_0}{w}\right),$$

where A is the sine amplitude, w the half-period, and y_0 and t_0 are the vertical and horizontal displacements. The fitting was done using the Levenberg-Marquardt algorithm. The goodness of fit was evaluated by means of the reduced χ^2, which is the χ^2 value divided by the number of the degrees of freedom, whose expected value is 1. None of the fitted data has shown a reduced χ^2 larger than 1.5. Multivariate ANOVA (MANOVA; SPSS statistical package version 15.0; SPSS, Inc., Chicago, IL) for repeated measure was used to investigate the effect of convergence level on the frequency and amplitude of the SOM.

RESULTS

The analysis revealed the SOM in the eye position signals at all four convergence levels; in Figure 1, sine fitting function (black line) presented the SOM track in the eye position signal (grey line). The mean and standard error of the SOM for the four convergence levels are shown in Figure 2.

The horizontal SOM displayed a lower frequency in response to the nearest target (cl 15) compared to the other three targets ($F_{[1,13]} = 4.741$, $P = 0.048$ for the dominant eye; $F_{[1,13]} = 5.517$, $P = 0.035$ for the nondominant eye). No significant difference was found among the other three convergence levels when analyzing the horizontal frequency. The frequencies of vertical SOM were not significantly different among the four convergence levels ($F_{[3,39]} = 0.506$, $P = 0.680$ for the dominant eye; $F_{[3,39]} = 0.477$, $P = 0.700$ for the nondominant eye).

The SOM amplitudes showed no significant difference among all four convergence levels in the horizontal meridian ($F_{[3,39]} = 0.728$, $P = 0.541$ for dominant eye; $F_{[3,39]} = 0.336$, $P = 0.799$ for nondominant eye) and in the vertical meridian ($F_{[3, 39]} = 2.257$, $P = 0.097$ for dominant eye; $F_{[3,39]} = 0.091$, $P = 0.964$ for nondominant eye).

DISCUSSION

Our study aimed at investigating if muscle tension had any influence on the SOM. Four horizontal convergence levels were used to modify EOM tension. The results showed that horizontal convergence significantly reduced the horizontal SOM frequency at the nearest fixation distance. Convergence is the first variable found to influence the SOM frequency. The SOM amplitude did not change in this experimental setup. The

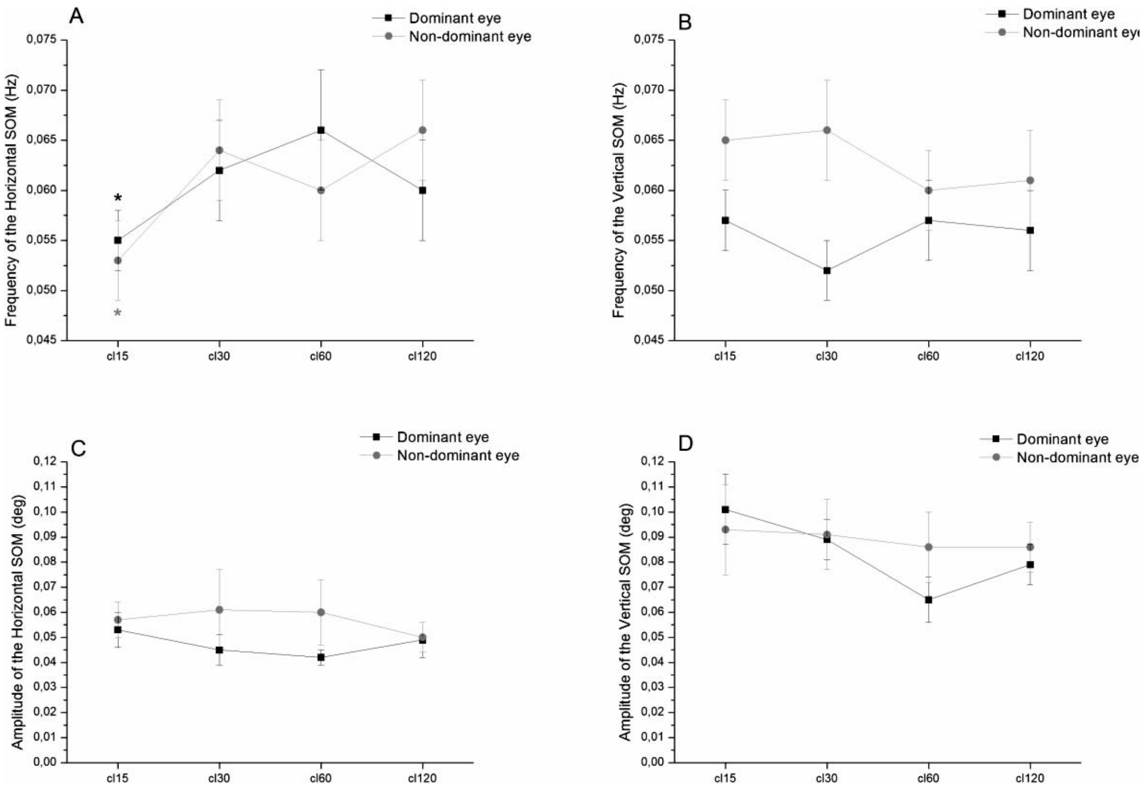

Figure 2. Graphs showing the mean values and standard errors ($n = 14$) for the horizontal SOM ([**A**] for frequency, [**C**] for amplitude) and vertical SOM ([**B**] for frequency, [**D**] for amplitude) in response to the four convergence levels. The frequencies of the horizontal SOM were significantly lowest in cl 15 compared to the other three convergence levels, for the dominant and nondominant eyes (**A**). In the amplitude plots (**C**, **D**), the dominant eye displayed larger amplitudes in the horizontal meridian and in the vertical meridian at near distance. No significant effect of the convergence levels was found.

results were consistent for the dominant and the nondominant eyes. In previous studies, we have reported that the spatial features of the visual target are capable of influencing the SOM amplitude solely.[7]

The horizontal SOM showed a longer period (i.e., reduced frequency) for the horizontal convergence at 15 cm visual fixation distance, while the frequency remained relatively constant at the other three distances. The effort needed to maintain clear vision at near distance is not related linearly to the target distance, but increases logarithmically with reduced distance for the accommodative and convergence system. A value of 15 cm is close to the near point of convergence. To maintain the eyes aligned at this close distance for 3 minutes certainly is difficult and might influence the gaze stability. Most subjects complained that it was hard to maintain clear vision at the nearest target (cl 15), and they felt fatigued after completing the test. A fatigue of the near response reduces the accommodative response, leading to a blurry target with enlarged diameter of the retinal image. Based on previous findings, a larger image would increase the SOM amplitude. These factors might explain the larger error bars at the nearest distance compared to the more remote fixations distances. The dominant eye exhibited slightly larger amplitude values for the nearest distance compared to the other three distances (Figs. 2C, 2D), although these differences were not significant.

Based on previous studies, horizontal convergence can modify the neuronal firing rate to the EOM.[5,8,9] Mays and Porter[8] used single-unit recordings in rhesus monkeys, and found that the abducens and oculomotor nuclei fire at a higher rate in convergence compared to when convergence relaxes, predicting a higher muscle tension during convergence, whereas Miller et al.[7] measured the LR and MR tension of monkeys in the asymmetric convergence, and presented reduced muscle tensions in LR, but a higher firing rate in the abducens nucleus with respect to the unconverged state. In their setup, the abducens nucleus contributes to convergence and conjugate states, so the neuron firing rate cannot be used to predict the muscle tension in convergence. Unpublished data from Lennerstrand and Campos, performing muscle tension measurements in awake patients, clearly demonstrate increased muscle tensions in the MR during symmetric convergence. We are lucky to have the recorded tension data from their co-worker, Bolzani, who also is a coauthor of this article. The highest degree of muscle tension was obtained at the nearest fixation distance. The muscle tension was kept nearly unchanged in the lateral rectus. How the LR tension changes in convergence seems controversial, while nobody questions the change of the MR tension in convergence.

In our study, we hypothesized that the degree of muscle tension in the MR increases with convergence angle. The muscle tension of the medial rectus has to overcome the lateral rectus tension and the elastic restoring tensions of the orbital content, otherwise the eye bulb will not rotate inward. The analysis of the horizontal SOM revealed a significantly slower frequency to the nearest convergence target. There might be a negative correlation between convergence and SOM frequency, but we could reveal only a significant difference to the nearest target with the method used in our study. We speculated that the quantitative change of the rectus tension only in the cl 15 is enough to produce influence on the SOM frequency.

The analysis of the vertical SOM did not reveal any significant differences to convergence. Mays et al.[10] hypothesized that superior oblique (SO) muscle relaxes during convergence movement, which reduces the eye's abducting tension to balance the insufficiently relaxed lateral rectus. According to Miller et al.,[5] the SO has a minor role in adduction. Our results did not reveal any differences in vertical SOM; the cyclovertical muscle tension does not seem to change sufficiently large to influence the vertical SOM.

The analysis of the dominant and nondominant eyes did not reveal any significant differences. That was in accordance with our expectation, since the two eyes receive identical convergence-related neural innervations[11–13] and were in the same eye position for the corresponding horizontal recti.

Conclusions

The frequency of SOM is related to the change of EOM tension. Our earlier findings showed that stimuli with little visual information can trigger larger SOM. We assumed that the control mechanisms for SOM come from two origins: EOM tension contributes to SOM frequency and visual perception contributes to SOM amplitude.

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References

1. Miller JM, Davison RC, Gamlin PD. Motor nucleus activity fails to predict extraocular muscle forces in ocular convergence. *J Neurophysiol*. 2011;105:2863–2873.
2. Allik J, Rauk M, Luuk A. Control and sense of eye movement behind closed eyelids. *Perception*. 1981;10:39–51.
3. Skavenski AA, Steinman RM. Control of eye position in the dark. *Vision Res*. 1970;10:193–203.
4. Winkler PA, Ciuffreda KJ. Ocular fixation, vestibular dysfunction, and visual motion hypersensitivity. *Optometry*. 2009;80: 502–512.
5. Miller JM, Bockisch CJ, Pavlovski DS. Missing lateral rectus force and absence of medial rectus co-contraction in ocular convergence. *J Neurophysiol*. 2002;87:2421–2433.
6. Zhang B, Pansell T, Ygge J, Bolzani R. Visual influence on the slow oscillatory eye movement discovered during a visual fixation task. *Vision Res*. 2011;51:2139–2144.
7. Pansell T, Zhang B, Bolzani R, Ygge J. Slow oscillatory eye movement during visual fixation. *Exp Brain Res*. 2011;209:1–8.
8. Mays LE, Porter JD. Neural control of vergence eye movements: activity of abducens and oculomotor neurons. *J Neurophysiol*. 1984;52:743–761.
9. Gamlin PD, Gnadt JW, Mays LE. Abducens internuclear neurons carry an inappropriate signal for ocular convergence. *J Neurophysiol*. 1989;62:70–81.
10. Mays LE, Zhang Y, Thorstad MH, Gamlin PD. Trochlear unit activity during ocular convergence. *J Neurophysiol*. 1991;65: 1484–1491.
11. Steffen H, Walker MF, Zee DS. Rotation of Listing's plane with convergence: independence from eye position. *Invest Ophthalmol Vis Sci*. 2000;41:715–721.
12. Allen MJ, Carter JH. The torsion component of the near reflex. A photographic study of the non-moving eye in unilateral convergence. *Am J Optom Arch Am Acad Optom*. 1967;44: 343–349.
13. King WM, Zhou W, Tomlinson RD, et al. Eye position signals in the abducens and oculomotor nuclei of monkeys during ocular convergence. *J Vestib Res*. 1994;4:401–408.