主　論　文

Effects of visually induced self-motion perception (vection) on upright standing posture.

（ヒトの直立姿勢に対する視覚誘発性自己運動感覚（vection）の影響）

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Abstract

This study examined the relationship between the magnitude of vection (visually induced perception of self-motion) and the forward body tilt induced by optokinetic stimulation (OKS). Twelve healthy adult subjects participated in this study. A moving random dot pattern as an OKS was projected on a large hemispherical dome screen placed in front of the subject. The pattern was moved downward on the screen. Each subject stood on a force-measuring platform in Romberg's position and gazed at a red fixation point in the center of the screen. OKS velocity in a range of 10 to 100 deg/sec was presented in random order. The magnitude of pitch vection caused by OKS was measured by the ten-point assessment method. The body sway values registered by the force-measuring platform were stored on a data recorder. After the antero-posterior component of body sway was converted by 12 bit A/D converter, a maximum point and average level of forward displacement of center of gravity caused by OKS was calculated by computer. Power spectrum analysis was applied for anterio-posterior body sway by the FFT method. From these analyses it was concluded that there was a close relationship between the magnitude of vection and the forward displacement of center of gravity caused by OKS. This suggests that the vection induced by moving patterns strongly modifies readjustment of the upright standing posture.

Keywords: Upright standing posture, Optokinetic stimulation, Pitch Vection, Readjustment of posture

抄　録

直立姿勢を維持した被験者に対して、視野の広い部分に動くパターン（視運動刺激、optokinetic stimulation ）を呈示すると、パターンの移動方向へ自己の身体の運動感覚（vection） を知覚すると同時に、パターンの移動方向への身体傾斜が誘発される。本研究においては、直径150 cmの半球状スクリーンの内側を、上方から下方へと移動するランダムドットパターンを被験者に呈示する事により、知覚されるvection の大きさと、誘発される直立姿勢の傾斜の大きさとの関係について検討することを目的とした。12名の健康な被験者が実験に参加した。被験者らは、暗室内においてRomberg 姿勢でforce platform上に直立し、前方に置かれた半球スクリーン中央の、赤色レーザースポットによる固視点を注視した。視運動刺激速度は、10deg/sec から100deg/secまでの範囲について、10 deg/sec毎の角速度を、無作為な順序で60秒間呈示した。vectionの大きさは10点表示法を用いて定量化し、口述により測定終了直後に報告させた。視運動刺激中の直立姿勢変化は、前後方向の重心動揺軌跡をA/D変換し、視運動刺激中における重心の前方移動量を計測し検討した。また、FFT 法により重心動揺軌跡の周波数解析を行った。視運動刺激中においては、直立姿勢の前傾と、一定刺激速度時における前傾維持姿勢が観察された（直立姿勢の再調節）。視運動刺激によって誘発された vectionの大きさと重心の最大前方移動量との間には密接な関係が認められた。これは、視運動刺激によって誘発される直立姿勢の再調節の大きさは、vection の知覚の大きさに依存することを示唆する。

INTRODUCTION

The upright standing posture of humans is controlled by visual, vestibular and somatosensory inputs. In Particular, the powerful stabilizing effect of vision on postural adjustment is well-known, and it has also been reported that postural control under weightlessness mainly depends upon visual information. The effects of visual inputs on upright standing posture have been clarified by observation of a slight change of postural instability provoked when the eyes are closed or in the dark. A pioneering report by Edward (1946)[10] showed that in this situation body sway increased markedly compared with when the eyes were open.

It is well known that large moving visual scenes cause the body to feel itself tilting opposite to the moving stimulus (Dichgans et al. 1972)[5]. Investigations on the visual contribution to body equilibrium using large moving visual scenes have been reported in many papers (Lee and Aronson 1974[15], Dichgans et al. 1976 [8], Lestienne et al. 1977[16], Mano 1979[18], Young et al. 1986[24], Ichikawa and Watanabe 1990[14]). The perception induced simultaneously by a large moving scene has been called a visually induced perception of self-motion or a vection (Fischer 1930)[12]. Vection induces body tilt and readjustment of upright standing posture (Lestienee et al. 1977)[16]. In the microgravity experiments of the SL-1 and D-1 Missions, the self-motion sensation, or the vection stimulated by a rotating dome, was enhanced and the visual orienting response become stronger (Young et al. 1986[22], 1990[23]). These reports suggest that the perception of vection may induce instability of posture and also may cause space motion sickness in microgravity.

A close relationship between the magnitude of vection and induced postural instability or readjustment is expected, but it has not been clearly showed. In this study we focused on quantitatively measuring the magnitude of pitch vection, and clarifying the relationship between the magnitude of vection and body tilt while moving a visual pattern over a large field.

METHODS

Subjects: Twelve healthy students (3 males and 9 females, aged 19 to 28) participated in this study. Subjects maintained an upright standing posture in Romberg's position during the experimental sessions on force platform (AMTI model OR6-5-1) which was placed in front of a hemispherical dome screen 150 cm in diameter .

Optokinetic stimulation (OKS): A random dot pattern projected inside the hemispherical dome screen was moved downward in a stream. The visual angle of the pattern was 70 deg horizontal and 180 deg vertical. The subject was instructed to gaze at a red laser spot fixation point about 0.3 degrees of the visual angle on the center of the screen. The gaze on the fixation spot was checked without eye movement to ascertain by EOG record. When nystagmus occurred, the vection and falling sensation was stronger than without eye fixation, and the occurrence of nystagmus differed greatly among individuals. We then used a fixation point in order to avoid a scattering of the data. Pattern velocities from 10 to 100 deg/sec, graduated in steps of 10 deg/sec, were presented in random order. After the subjects stood on the force platform, they were exposed to the visual stimulus for 80 sec, the first 20 sec being an acceleration phase, and the following 60 sec a constant velocity phase and an abrupt stop. Measurement was conducted throughout the period of stimulation, as well as during the 60-sec prestimulation and also the 60-sec post-recovery phases. This measurment was carried out in the dark room.

Expression of vection: A perception of self-motion induced by a moving visual scene was defined as vection. In this study, the magnitude of vection was estimated by a combined sensation of the magnitude and velocity of the movement of the fixation point against the visual scene. A ten-point assessment method by magnitude estimation (Stevens, 1957[21], Lipetz, 1971[17]) was used for the quantitative measurement of vection. It was graduated with a maximum of 10, 0 being without vection during the stationary pattern. The subjects were well trained for the ten-point assessment by being presented various moving pattern velocities before the test.

Measurement of body sway: Two-dimensional antero-posterior and lateral body sway components were measured by means of the force-measuring platform. The recordings were drawn simultaneously on chart paper and stored on a data recorder (TEAC XR-50). The antero-posterior component of body sway was sampled at 20 Hz by means of an A/D converter, and processed by computer. The maximum point and the average level of forward displacement of the center of gravity caused by OKS were estimated as a base for an average level in the pre-stimulation phase. Body sway power spectra were calculated using the FFT method.

Head displacement was recorded in three dimensions using a head sway analyzer (SAN-EI Co.Ltd) consisting of an ultrasonic oscillator and a detector. In the present experiment only the antero-posterior component on the horizontal plane was analyzed. The vertical EOG was monitored with silver plate electrodes placed above and below the right eye. EMGs were bipolarly derived from the soleus muscle and the tibialis anterior muscle.

In this experiment, one experimental session was composed of 11 trials with a resting period of 5 to 10 minutes for each trial. To examine the effects of habituation of vection, the OKS which produced maximum vection at the first trial of the session was repeated at the final trial.

RESULTS

The subjects clearly perceived a self-motion sensation which occurred simultaneously as a fixation spot moving the opposite direction of the stream of the random dot pattern, and their bodies inclined forward and reset to a new balancing standing posture while the random dot pattern moved downward. Figure 1 shows four examples of antero-posterior displacement of center of gravity (CG) before and during OKS and the aftereffects. Individual differences in CG patterns of displacement in response to OKS were varied but closely approximated the pattern of stimulus velocity. With the start of OKS, the subject's body gradually inclined forward. The body inclination was maintained in a stationary position when the velocity of OKS became constant. As soon as the OKS was stopped abruptly, the CG

Fig. 1

immediately began to return again to the initial position in all subjects. Almost all subjects showed a large body sway with a backward counter-sway as an aftereffect immediately after the stop of OKS.

Figure 2 shows the reproducibility of the pitch vection and maximum forward body inclination induced by OKS. The magnitude of vection and maximum forward displacement of CG were compared with the first and final trials under the same experimental conditions. There was a slight decline in the magnitude of vection between the first and the final trials. However, for maximum forward CG displacement the decrease was not statistically significant. Fig. 2

An oscillatory body sway was observed in the forward body inclination during constant velocity stimulation. A spectral analysis of the body sway in this period showed increased power at the frequency range of 0.1 to 8 Hz in which remarkable increases were detected at three peaks around 0.2 Hz, 1.0 Hz and 4.0 Hz as shown in Figure 3C. Fig. 3

Figure 4-A shows the power spectrum expressed by the ratio of the body sway without OKS and during OKS at a velocity of 60 deg/sec, and Figure 4-B shows that of the body sway caused by the voluntary forward leaning of the body to the same level of the body inclination at the OKS velocity of 60 deg/sec. These data were obtained as average values of the same 5 subjects. Though an increase of the frequency range of 0.2-0.7 Hz was found during body inclination induced by OKS, the increase of the low frequency range at around 0.7 Hz disappeared in the power spectrum during voluntary body inclination. The increase in spectral power of the low frequency range of less than 1 Hz Fig. 4

corresponded with the visual contribution.

The change of forward CG displacement corresponding to the increasing velocity of OKS is shown in Figure 5. The maximum forward CG displacement during OKS was gradually increased up to 60 deg/sec, and gradually decreased with higher velocity until the maximum velocity was tested at 100 deg/sec. The same tendency was found in the average CG displacement during OKS. Fig. 5

As shown Figure 6 the magnitude of vection for the mean value of all subjects increased gradually with the increase of angular velocity up to 50 deg/sec , and showed a peak value at the range of 50 to 70 deg/sec of angular velocity, then decreased with a range of 80 to 100 deg/sec. Fig. 6

Figure 7 shows an example of the change of the maximum and average forward displacement and magnitude of vection with the increase of angular velocity of OKS of two subjects. Subject KAN showed an abrupt decrease of vection at the higher velocity (upper part of the figure), and subject SAT showed a magnitude of vection maintained at a high level at the higher velocity. A close relationship between the magnitude of vection and the forward displacement of the center of gravity was clearly found in these two examples. Fig. 7

The relationship between the magnitude of vection and the forward CG displacement during OKS in all subjects is shown in Figure 8. The correlation coefficient of both relationships was 0.649 ($p<0.001$). Fig. 8

The time course of head sway, especially in the antero-posterior direction, was almost similar to that of body sway. An increase in continuous tonic and also phasic activities of M. soleus occurred during the forward body inclination caused by OKS. The relationship between muscle activity and body sway will be reported elsewhere.

DISCUSSION

The perception of self-movement (vection) and body inclination induced by a large moving visual stimulus were systematically investigated by Dichgans and Brandt (1978)[9] and Lestienne et al. (1977)[16]. They used a moving visual stimulation which induced a roll vection[9] and a linear vection[16]. In this study, we used a visual stimulation which rotated to pitch direction. With the downward movement of a random dot pattern a pitch vection and a forward body inclination with antero-posterior body sway provoking the dorsi-flexion of ankle joints were induced.

Quantitative measurements of vection have appeared in many papers (Dichgans et al., 1973 [6], Brandt et al., 1973[2], Berthoz et al., 1975[1], Schor et al., 1984 [22], Young et al., 1986[24], 1990[25], Cheung et al., 1990[15]). The method we used made it easy to train the subjects and to assess the magnitude of perception for visual stimulation while in an upright standing posture. The magnitude of vection increased with the increase of stimulus velocity up to 70 deg/sec, and decreased the range from 80 to 100 deg/sec of OKS velocity. Dichgans et al. (1973)[6] and Held et al. (1975)[13] reported that the perception of tilt of a straight edge during roll vection reached the maximum value at 30 to 40 deg/sec of pattern velocity. Brandt et al. (1973)[3] reported that the sensation of exclusive self-motion elicited by a moving visual stimulus showed its upper limit at approximately 90 deg/sec. In this study, almost all subjects reported a sensation of fusion of the random dot pattern when 70 deg/sec of OKS velocity was exceeded. Then this may have induced a decrease of vection at a high OKS velocity. This point corresponds to the OKS velocity of the optokinetic adaptation limit of optokinetic nystagmus.

We reported that the postural change induced by OKS has a high reproducibility[14]. The same result for the forward CG displacement induced by OKS was also obtained in this study. The magnitude of vection, however, slightly decreased in final measurement of the 11th trial, in which the repeated visual stimulation might have caused a habituation of the vection due to an underestimation of the same intensity.

When the OKS was presented to standing subjects, forward body inclination was induced with the start of OKS. Then, there was a postural readjustment control at the constant velocity phase of OKS. The body inclination increased with the increasing velocity of OKS up to 60 deg/sec, and the maximum value was found at 60 to 70 deg/sec of OKS velocity. Dichgans et al. (1976)[8] reported a reflex-like reaction body sway and tonic tilt eventually towards the direction of image motion when a large visual scene was rotated about the subject's line of sight. Lestinee et al. (1977)[16] also reported that the saturation of the amplitude of postural readjustment was observed at a higher image velocity. He suggested that the saturation of postural readjustment was related to the saturation of linear vection. This relationship was also observed with the pitch vection stimuli in this study.

A large antero-posterior CG oscillation was generated in the forward body inclination during a constant velocity of OKS in this study. The antero-posterior body sway during OKS was characterized by a relatively low frequency of 0.2-0.7 Hz and sometimes observed a middle oscillation frequency of around 1 Hz and a high frequency range of 4-8 Hz. Dichgans et al. (1976)[8] reported that a peak at 0.6 Hz of body sway was produced by roll vection stimulation and he suggested that it might be the resonant frequency of the posture stabilizing system during the time the vection is produced. Lestienne et al. (1977)[16] reported an increase of the frequency range between 0.15 and 0.5 Hz for linear vection stimuli. These low frequency ranges were also found in this study; however, an increase in spectral power of the body sway during voluntary body inclination without OKS was not apparent. Therefore, we concluded that the low frequency of body sway was influenced by OKS.

Mauritz and Dietz (1980)[19] have referred to the frequencies around 1 Hz corresponding to the frequency domain of vestibular postural control. Dietz et al[10] reported that body oscillations of 4-5 Hz were observed under conditions in which the subject was balancing on a seesaw, and suggested that this oscillation was mainly induced by segmental stretch reflexes. Dichgans et al. (1976)[8] emphasized that a higher frequency of peak at 2.5-3 Hz was found in patients with cerebellar atrophy. Moreover, the physiological tremulous frequency was also found in upright standing, especially in a fatigue situation (Mori et al.[21]). In our previous experiment[20], forward leaning induced an increased body oscillation in the same high frequency ranges. These results may suggest that high frequencies of body oscillation were induced mainly by the afferent information from the lower legs. Two or three characteristic increases in body sway during forward inclination produced by OKS in this study can be explained by the hypothesis that the lower frequency component may involve the visual influence and the higher frequency oscillation may be due to control of vestibular and proprioceptive systems.

A high correlation was found in the relationship between the magnitude of vection and the forward body inclination induced by OKS. Therefore it may be concluded that the vection induced by OKS causes the body to incline, and the righting reaction occurs with the processing of labyrinthine and somatosensory information, which involve the proprioception from the antigravity muscles, joint sensation and also from deep sensation of the sole skin. The subjects particularly perceived the pressure at the soles which was increased with the increase of body inclination during forward inclination. Hence, it is suggested that the information for the magnitude of the pressure of the sole might be also useful for postural readjustment during OKS.

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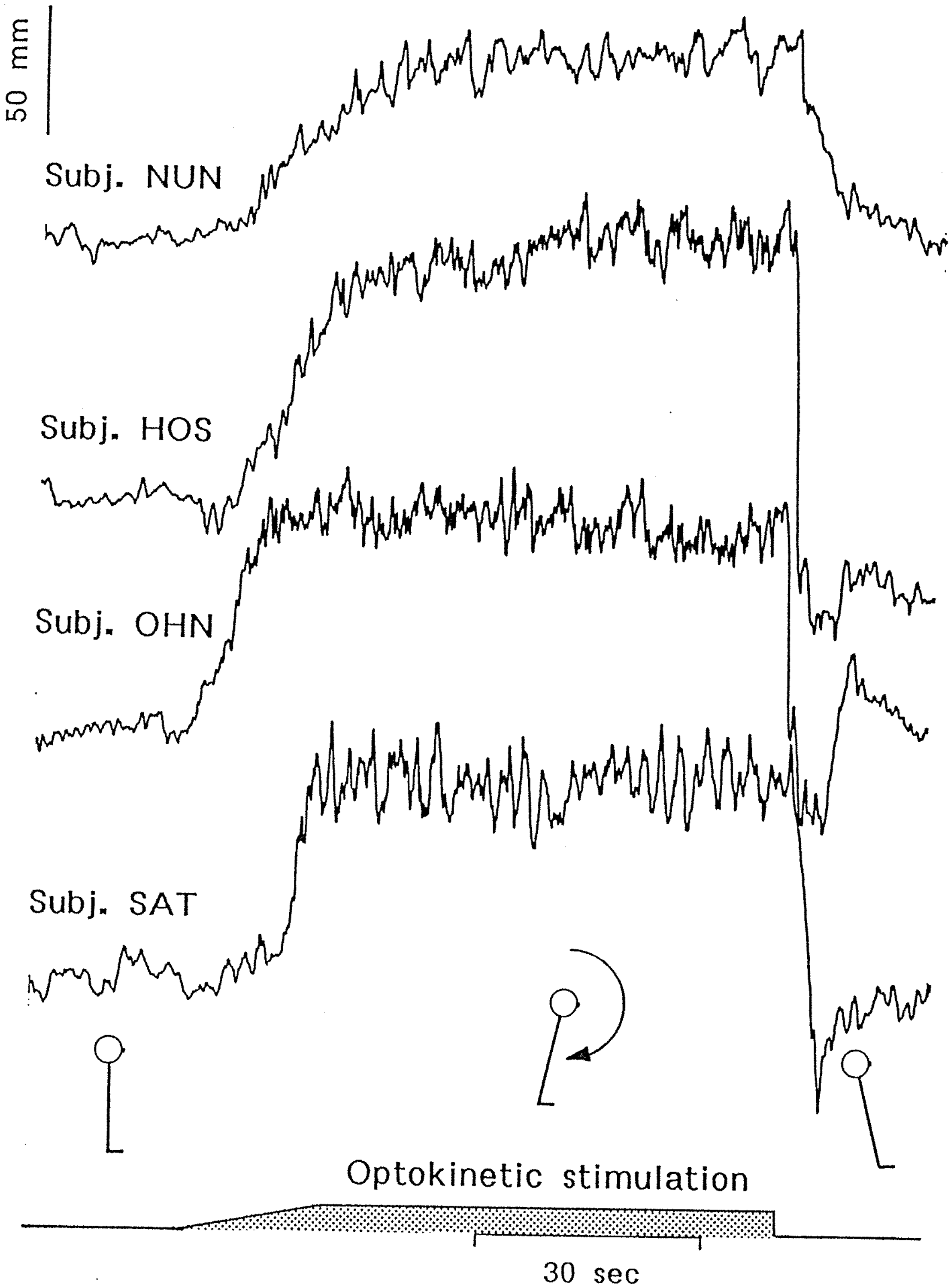
Fig. 1



50 mm
Subj. NUN
Subj. HOS
Subj. OHN
Subj. SAT
Optokinetic stimulation
30 sec

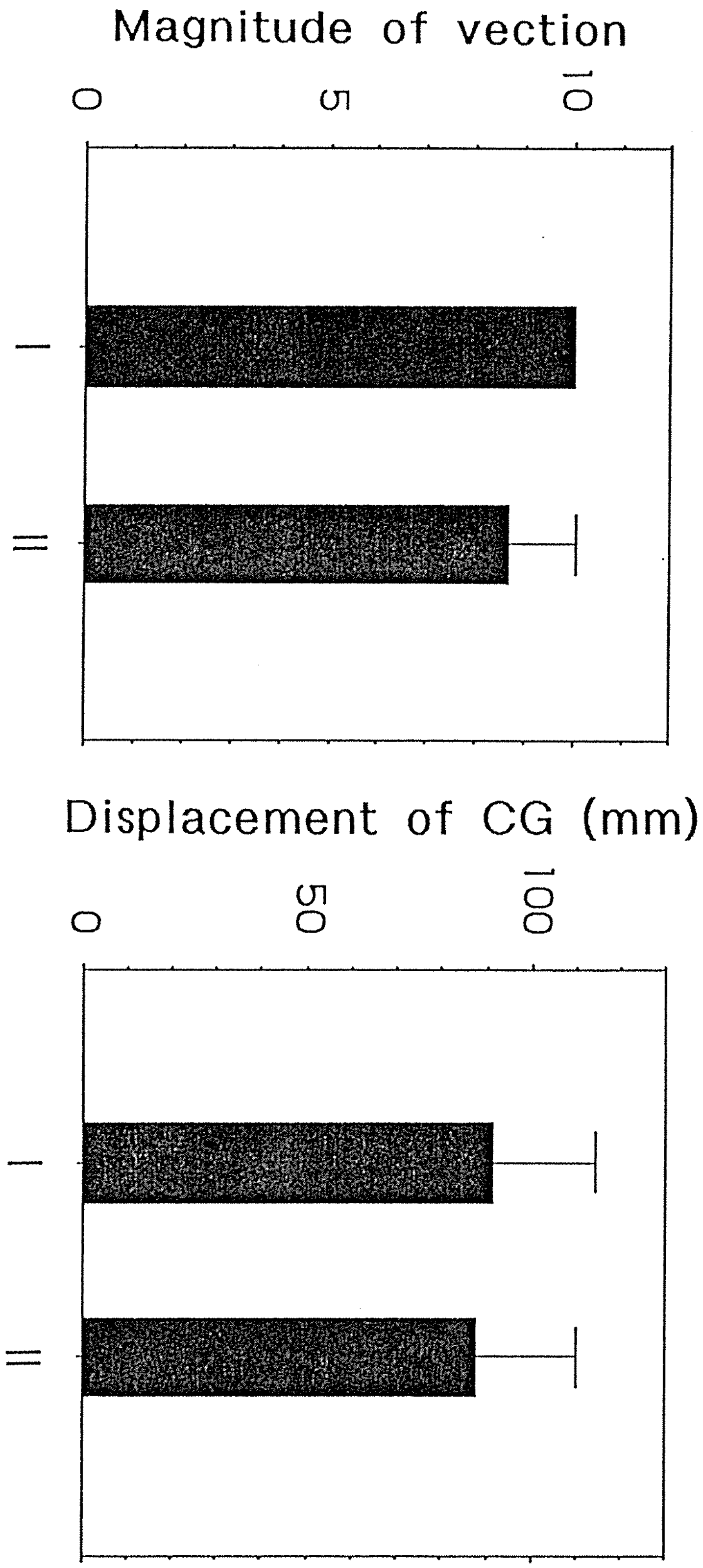

Magnitude of vection
0
5
10
I
II
Displacement of CG (mm)
0
50
100
I
II

Fig. 2

Fig. 3

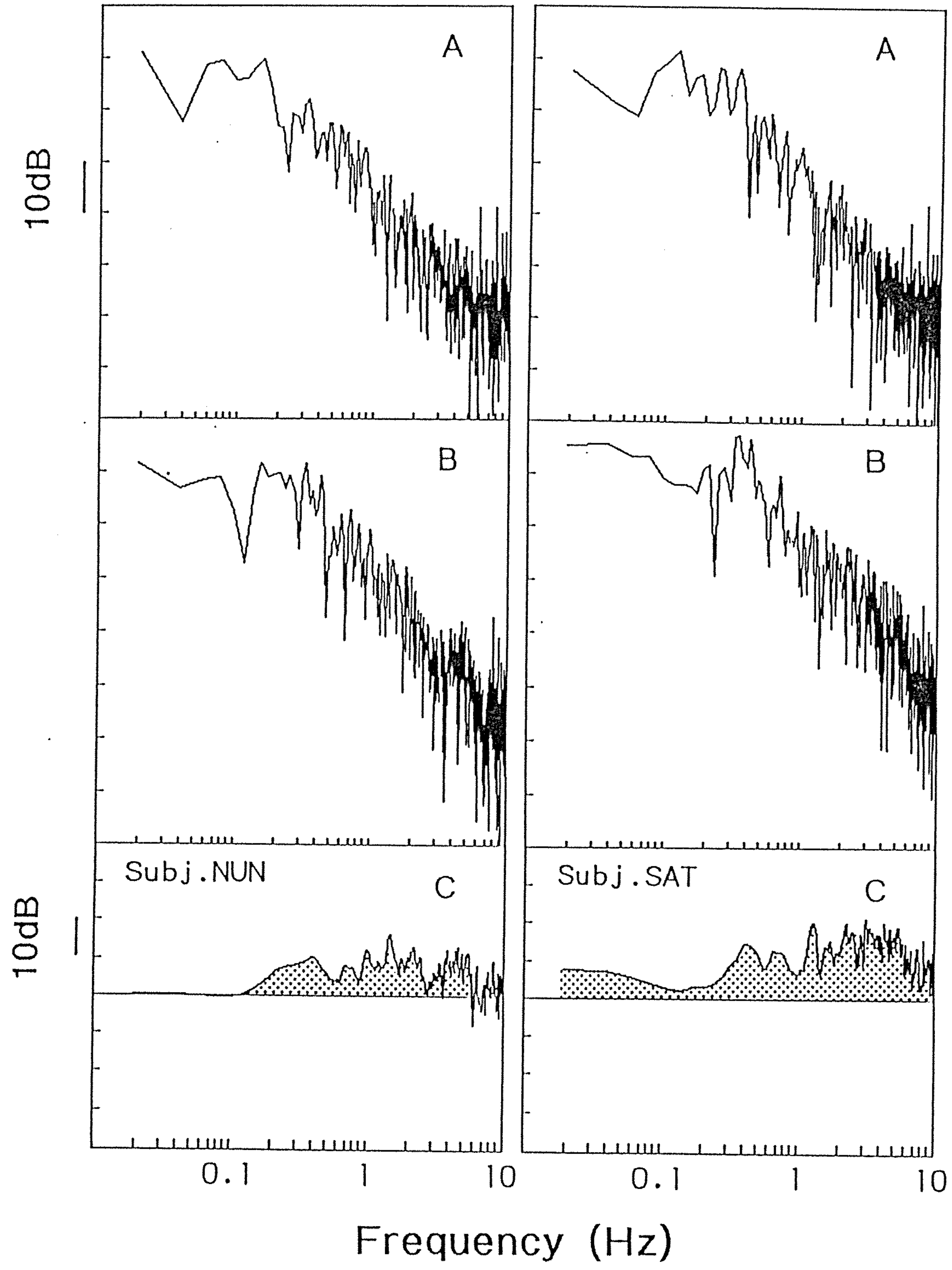


Fig.4

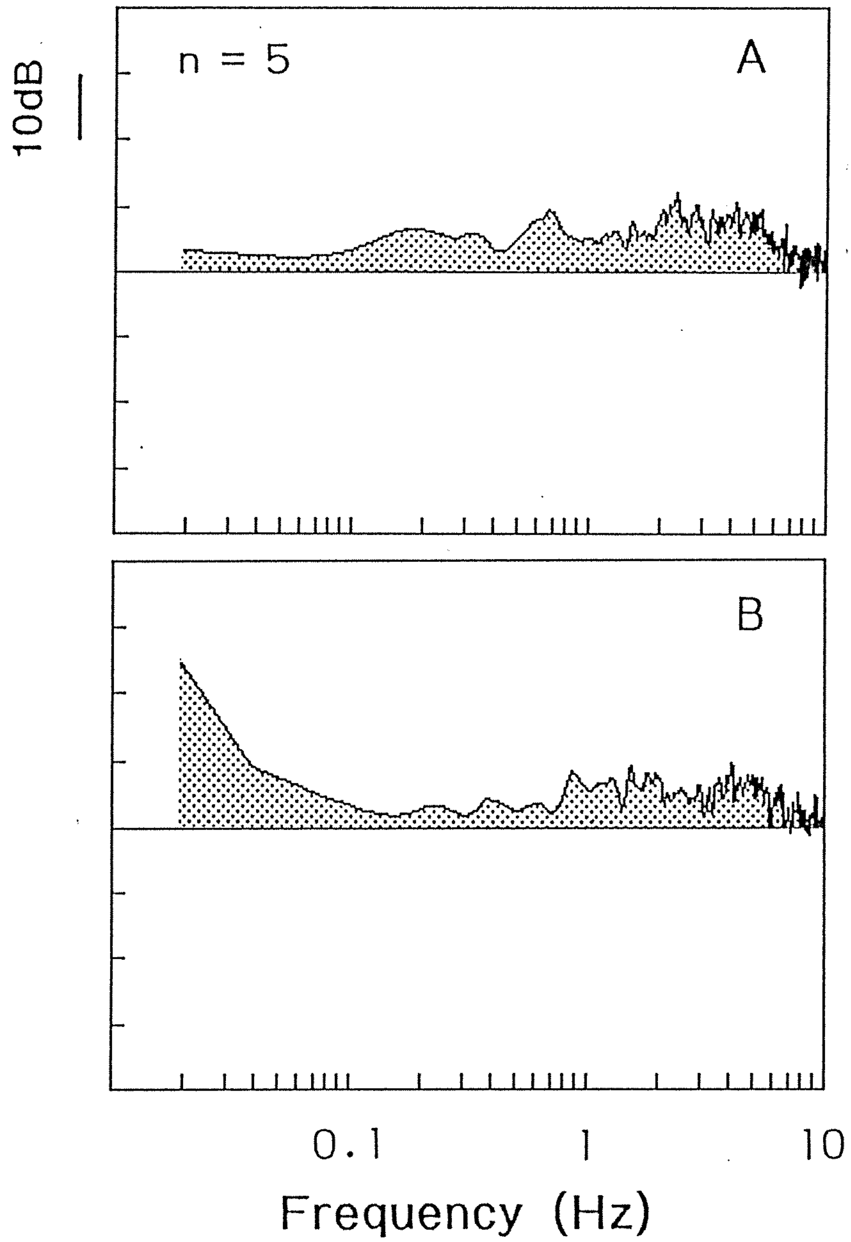
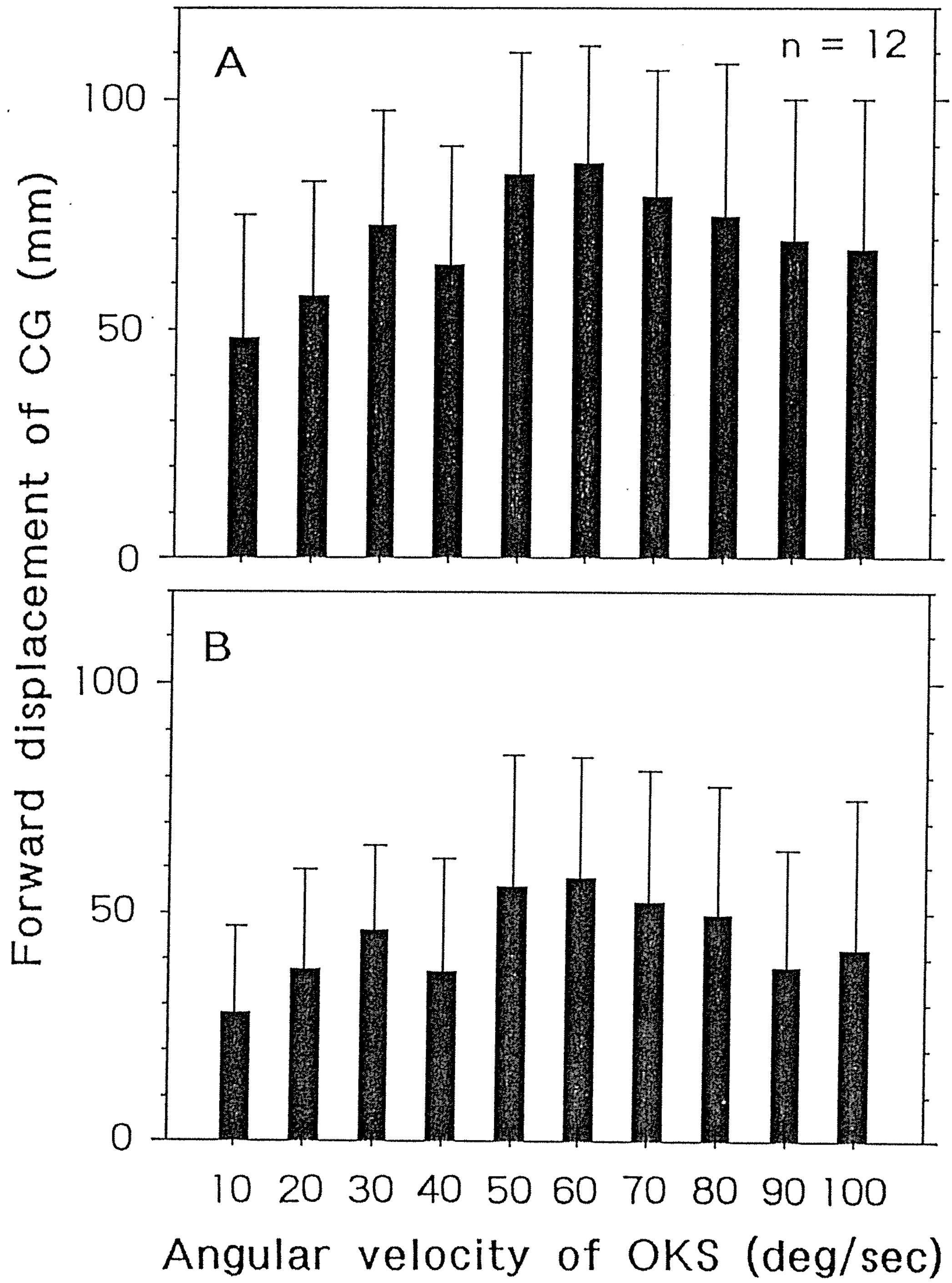
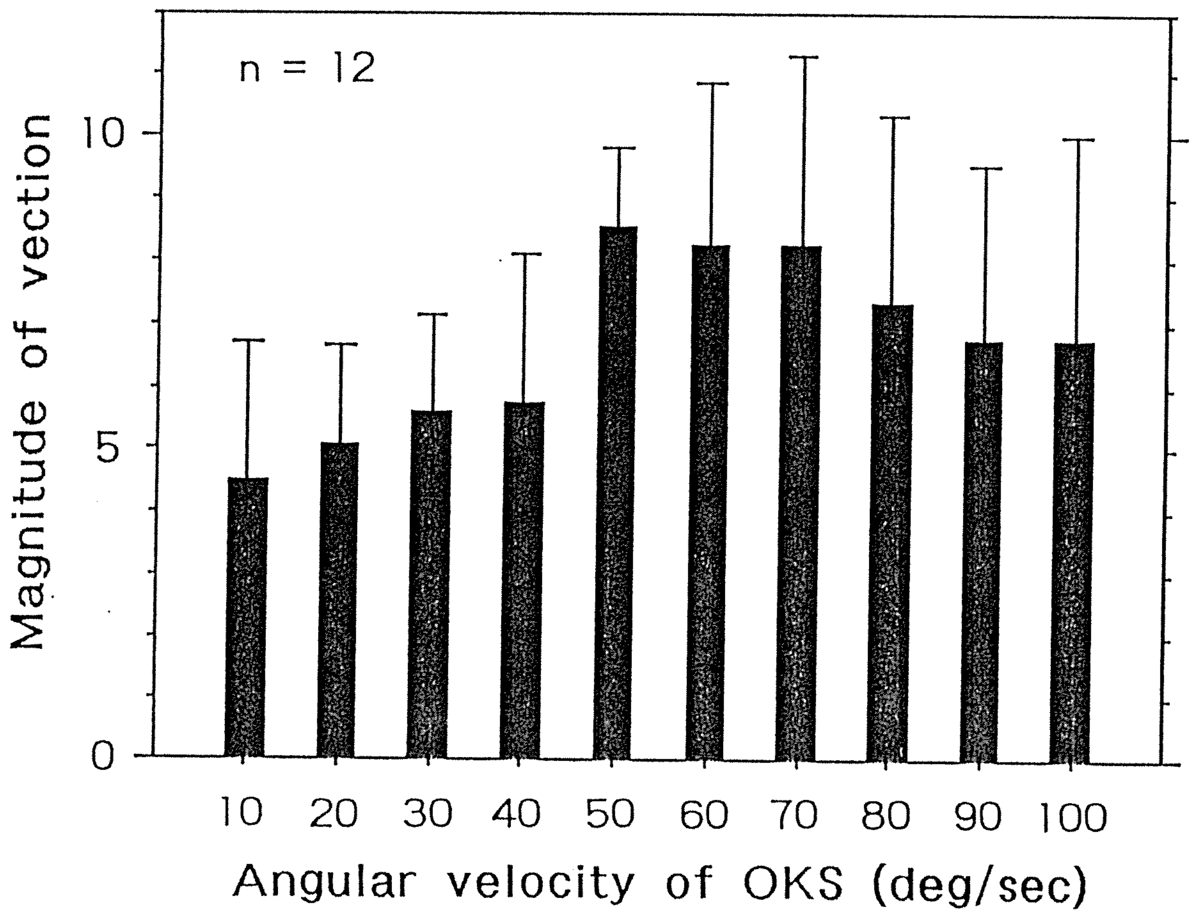


Fig. 5



A
n = 12
B
100
50
0
100
50
0
Forward displacement of CG (mm)
10 20 30 40 50 60 70 80 90 100
Angular velocity of OKS (deg/sec)

Fig. 6



n = 12
Magnitude of vection
0
5
10
10
20
30
40
50
60
70
80
90
100
Angular velocity of OKS (deg/sec)

Fig. 7

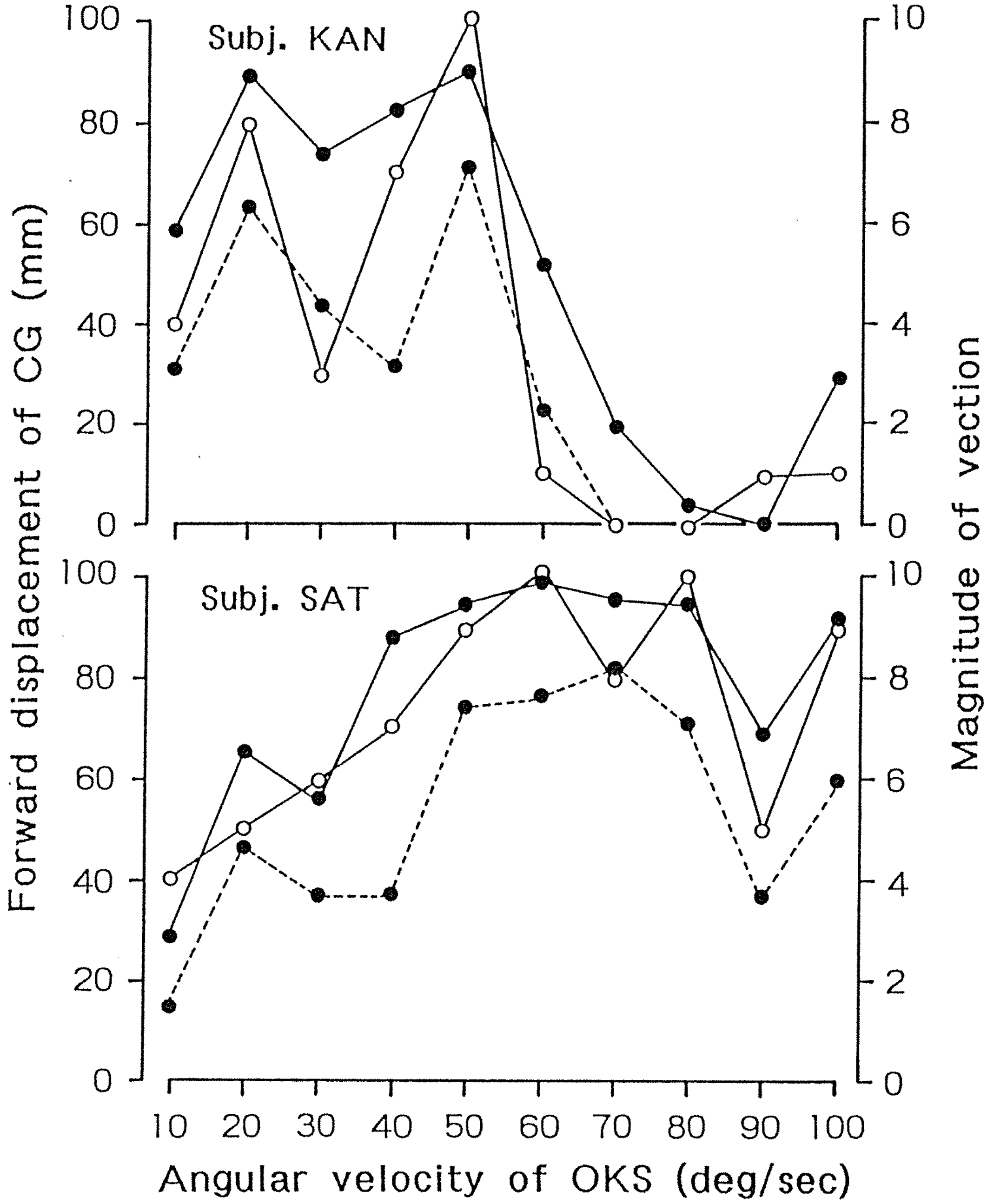
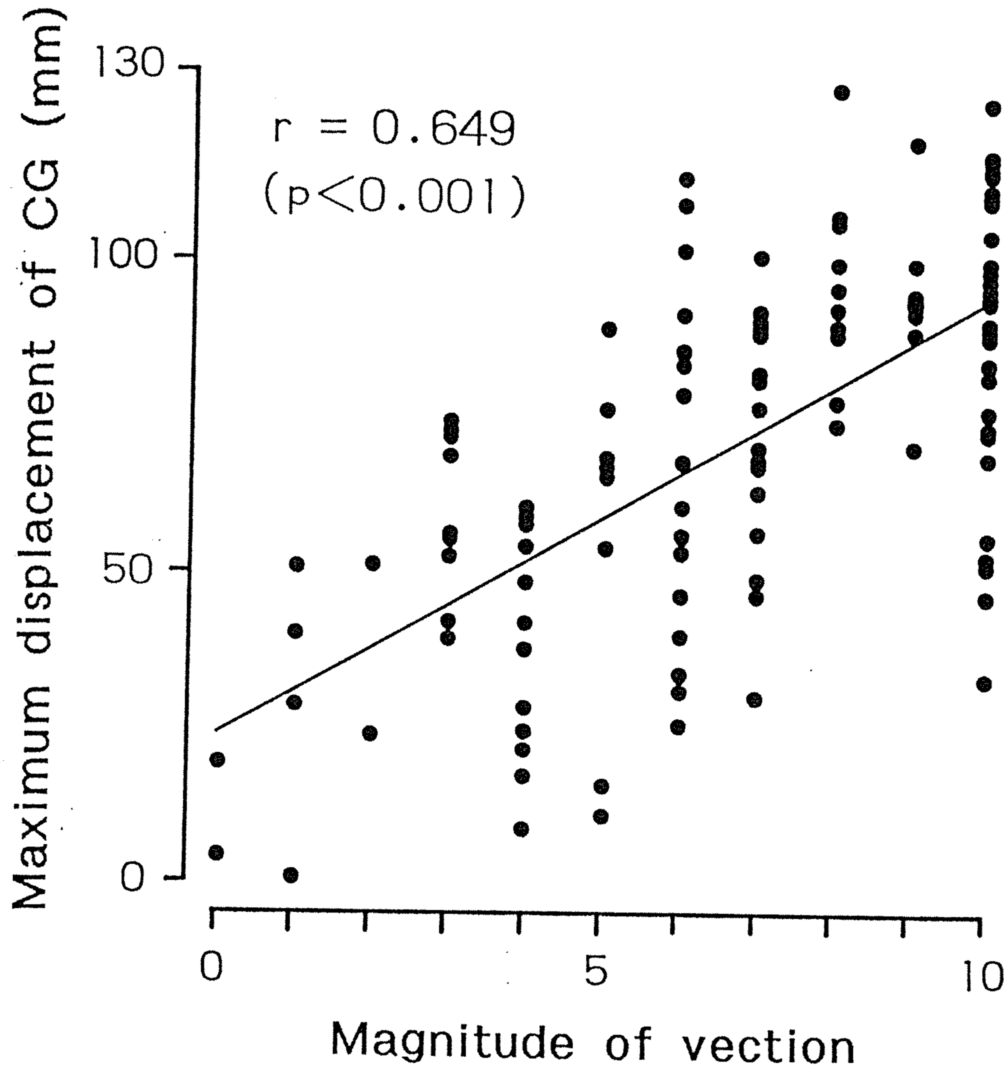

Subj. KAN
Subj. SAT
Forward displacement of CG (mm)
Magnitude of vection
Angular velocity of OKS (deg/sec)
0
20
40
60
80
100
0
2
4
6
8
10
10
20
30
40
50
60
70
80
90
100

Fig.8



Maximum displacement of CG (mm)
130
100
50
0
r = 0.649
(p<0.001)
0
5
10
Magnitude of vection

Figure 1. Time course of induced forward displacement of center of gravity during optokinetic stimulation for four subjects. The constant angular velocity was 60 deg/sec.

Figure 2. Reproducibility of magitude of vection (left side) and maximum forward displacement of CG (right side). I shows the 1st measurement of the series. II shows the last measurement (11th) of the series.

Figure 3. Power spectrum density of antrior-posterior body sway for two subjects. A shows the power spectrum of body sway without stimulation. B shows the power spectrum of body sway during OKS. C indicates the ratio of the power spectral density of A and B.

Figure 4. Power spectra of postural sway expressed by the ratio of the forward body inclination induced by OKS to the upright standing (A) position, and the ratio of the forward body inclination by voluntary leaning to upright standing (B) position. Mean power spectra of five subjects are shown.

Figure 5. Change of maximum (A) and average (B) forward displacement of center of gravity with increase of angular velocity of OKS. Values indicate mean and standard deviation.

FIgure 6. Change of the magnitude of vection with an increase of angular velocity of OKS. Values indicate mean and standard deviation.

Figure 7. Two examples for change of the maximum and average forward displacement of center of gravity (closed circle) and the magnitude of vection (open circle) with an increase of the angular velocity of OKS. Results of subjects KAN and SAT are presented in this figure.

Figure 8. The relationship between the magnitude of vection and the maximum forward displacement of center of gravity.

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