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Effects of Visual Field Restriction on the Stability of Human Head Position During Walking

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The stability of human head position during walking was investigated, using angular velocity sensors, with emphasis on the effects of restriction of the visual field. The results (i) confirm the stability of head position during normal walking and (ii) demonstrate the importance of information from the peripheral visual field, as seen by differences in the amplitude of head movements. The effects of searching behavior on the head movements are discussed.

KEYWORDS: human walking, orienting and searching behavior, stability of head position, visual field

INTRODUCTION

Animals require information about the spatial orientation of their environment for many basic activities, such as feeding, grooming, catching prey and escaping from predators. The head is the positional center as well as the functional center of spatial orientation and, since the sensory organs are located in the head, it therefore serves as the origin of the space coordinate system. Head movements are highly effective ways to obtain more information about the environment, but such movements also cause perturbation of the origin in spatial perception. In addition to this, discrimination between object motion and self motion (through retinal information) is confused by head movement. From this paradoxical property of head movements, it is reasonable to suppose that there are two types of head movements: searching and orienting.

Head movements play an important role in spatial orientation in vertebrates and many invertebrates but it is desirable that head position is stable during orienting behavior. Wehner (1992) described the constant head position of *Cataglyphis* (a species of ant), which maintains a constant pitch position of the head during walking without a load or while carrying a heavy load. Neuroanatomical and electrophysiological studies suggest that the part of the eye directed skywards detects polarized light patterns. This area functions as the compass which aligns with the celestial hemispheres. Wehner (1992) pointed out that ants also show rotation of the body to scan the skylight pattern for transferring information from the space domain to the time domain.

In experiments performed in pigeons, Erichsen *et al.* (1989) described an example of constant head position in birds. They investigated head position during many activities and found that the head is held at a similar angle to the horizontal during flight, walking, perching and standing. Fitzke *et al.* (1985) showed that there are functional differences between the upper and lower visual fields of pigeons. The upper and horizontal visual fields are emmetropic for objects and increasingly myopic at angles in the lower visual field. They also suggested that the constant head position is effective in keeping the ground in focus during walking and standing, and to keep the horizon, but not the ground, in focus during flight. The report by Green et al. (1992), which points out that head position is changed during the landing approach to keep the perch in focus, supports these findings.

Berthoz and Pozzo (1988) analyzed many photographs taken by Muybridge and found that the human head is stabilized in space during climbing stairs, walking and running. They also obtained experimental data of body movements during walking. Using measurements made with an image processing system, they found that the angular position of the head is stabilized in space within a few degrees. However, there are still many details concerning the stability of human head position during walking which require clarification. The comparative findings summarized above concern the function of different regions of the visual field, and here we provide data to examine the functional differences in the human visual field.

Many studies have been performed on the functional differences between central and peripheral visual fields, concluding that the information from the peripheral visual field plays an important role in spatial orientation. It is supposed that peripheral visual field information is also important for head movement. Previc (1990) stated that the lower visual field is more important in the perceptual systems required for visuomotor coordination in peripersonal space, and that the upper is linked with the visual search and recognition mechanism directed toward extrapersonal space.

The aims of this paper are to follow up the finding on the stability of head position in humans and to analyze the role of information from different regions of the visual field on head position during walking. A preliminary analysis of eye-head coordination in several visual field conditions during walking in humans was reported recently (Horikawa, 1994). The analysis reported here includes data on head movements as well.

METHODS

Subjects

One male and four female subjects between the ages of 21 and 23 were recruited from a university to participate in the study. All subjects were screened for good health.

Apparatus

Control of the visual field was obtained using four designs of plain-lens spectacles, allowing perception of: (i) the upper half of the visual field (UPPER); (ii) the lower half (LOWER); (iii) monocular right visual field (RIGHT); or (iv) approximately 14 degrees of the right central visual field (CENTRAL).

Three components of head movement (yawing, pitching and rolling) were measured with angular velocity sensors (Murata, ENV-05S), the signals from which were recorded on a PCM data recorder (NF Circuit Design, No. 5870). The output from the data recorder was digitized (12 bits A/D conversion, 100 Hz sampling rate) and processed with a signal processor (NEC San-ei, DP-1100).

Procedure

Subjects were fitted with light-weight head gear containing the angular velocity sensors. The experimental arrangement allowed the subjects to stand freely in the center of a straight corridor (width 2.5 m). They were asked to walk in their usual posture and at normal pace. The walking distance was 25 m and the analysis region was from one to 24 m, i.e. a total of 23 m, excluding the initiation and termination of walking. In the control conditions (FLAT), subjects walked straight along the corridor wearing one of the four types of custoni-made

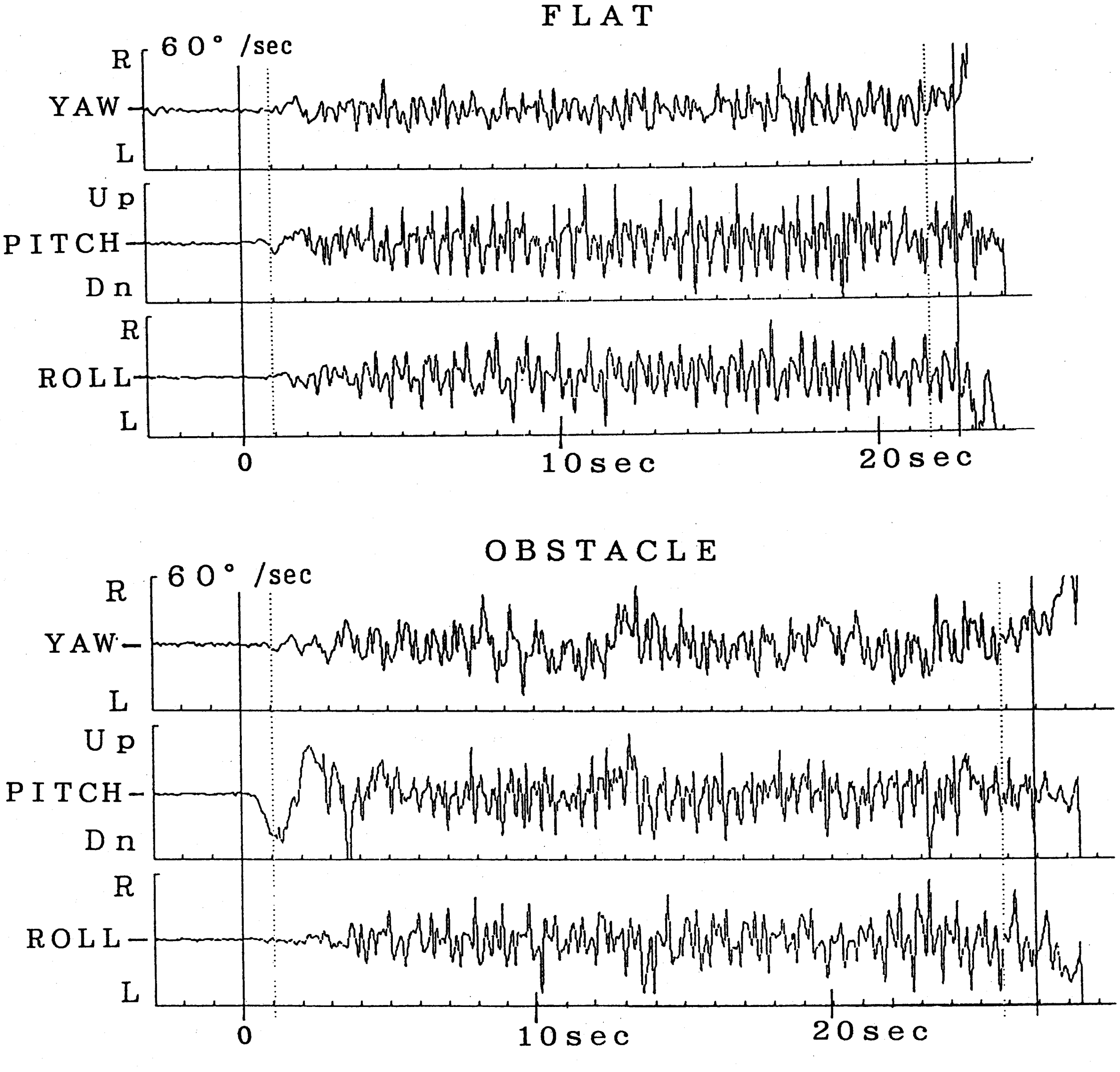

Fig. 1 An example of the pattern of angular velocity of head movements during walking (Condition: UPPER, Subject: YM).

spectacles restricting the visual field. A preliminary trial (PRE), where the subject walked without wearing glasses was used to obtain basic data for comparison. After the main trials, data were obtained without glasses (POST) to examine the effects of fatigue.

In the experimental conditions, six thin black patches (10 cm diameter) were placed along the center of the corridor at random intervals and the subjects were instructed to walk without stepping on or over the patches (OBSTACLE). The experimental trials were conducted under the four restricted visual field conditions described above, and the no spectacles condition (FULL), in random order.

Data Analysis

The head movement data were calibrated before trials using tracking movements of the head of seated subjects. The subjects wore an eye mask with a pin-hole for the right eye and were asked to track from the central point of a vertical cross to one of five targets points set at intervals along each of four directions: right, left, up and down. The head position was calculated by integration of angular velocities in three dimensions and corrected by computing a least-square linear regression. The base position was calculated as the average position during three seconds before the start of walking.

RESULTS

An example of the angular velocities of head movements and calculated head position is shown in Figs. 1 and 2. In these figures, the solid vertical line shows the walking region and the dotted vertical line shows the analysis region.

Angular velocity

Mean angular velocity for all conditions was 38.4 deg/s with a maximum of 80.02 deg/s. The waves of angu-

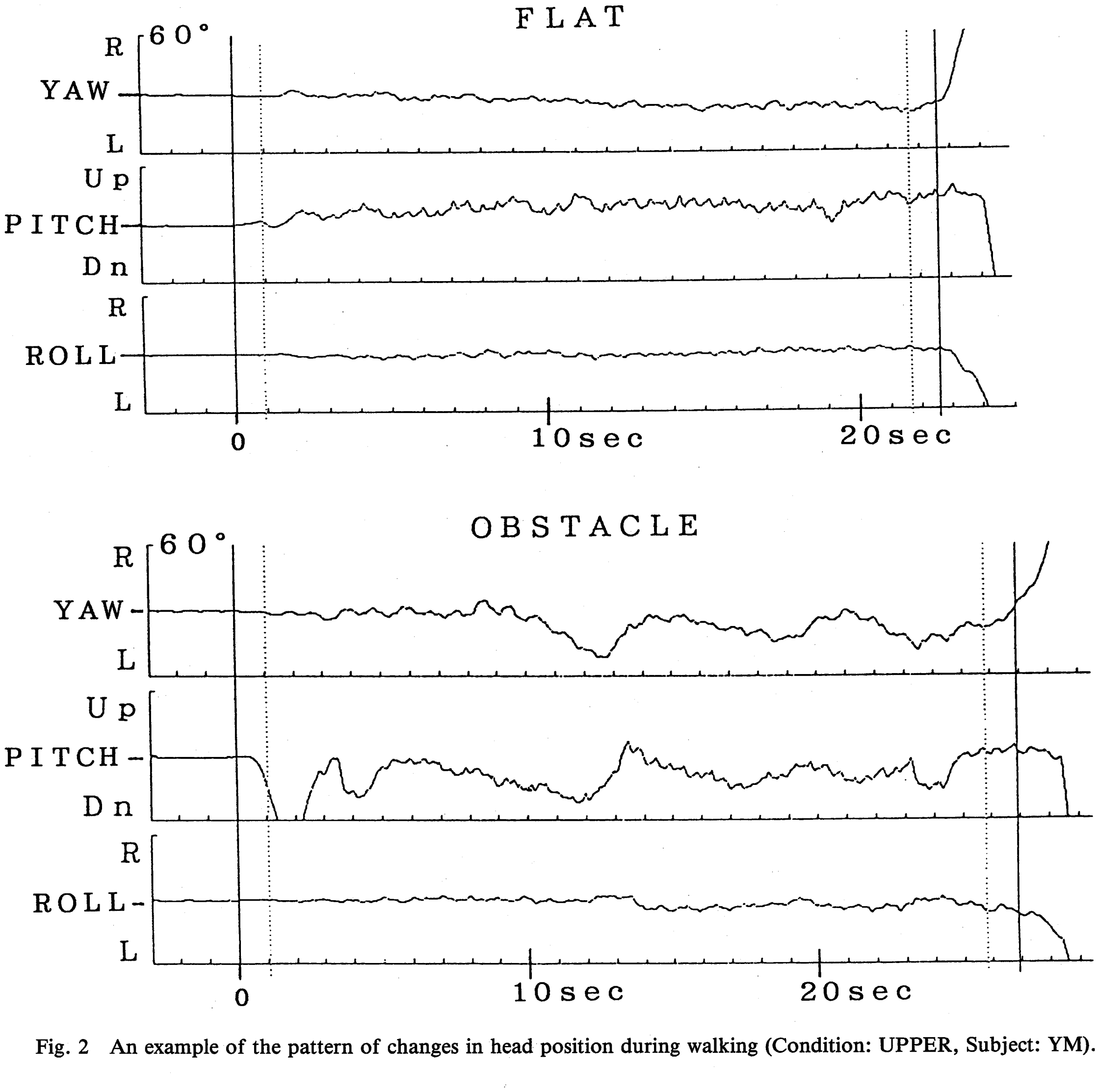

Fig. 2 An example of the pattern of changes in head position during walking (Condition: UPPER, Subject: YM).

lar velocity in Fig. 1 suggest a regular cycle of head movements for all three components in FLAT, but in the OBSTACLE condition there was less regularity and increased maximum and minimum values of angular velocity.

Head position

Figure 2 shows that the changes of head position were small for FLAT but very large for OBSTACLE. The effects of having a searching task to perform are clearly shown in the figure. At present there is no standard measure of the stability of head movement. Tentatively, the standard deviation of head position is used as the measure of stability of head movement (MSH) in this report. Mean and standard deviations of MSH for all subjects are shown in Fig. 3. The MSH values of the three components for PRE were all less than four degrees. The MSH for FLAT did not exceed ten degrees, except with CENTRAL, and was smaller than for OBSTACLE. The largest change of MSH among the four restricted visual field conditions was observed with CENTRAL.

Frequency analysis

A sample of the results of frequency analysis with the FFT (Fast Fourier Transformation) method in same UPPER conditions is shown in Fig. 4. The figure shows that the relative power ratio ranged from 0.098 Hz to 9.8

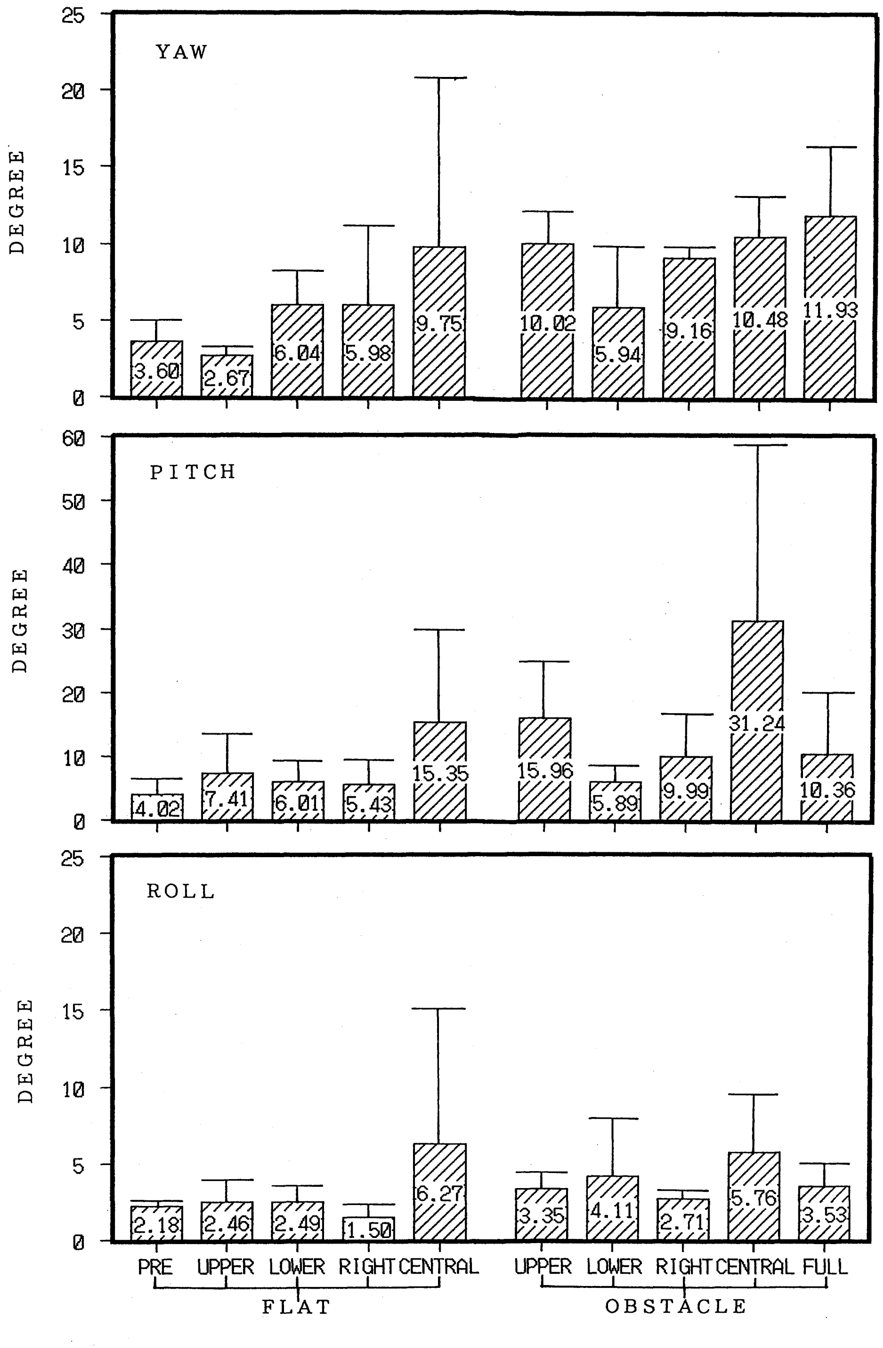

Fig. 3 Mean and SD of the measure of stability of head movements in 5 subjects.

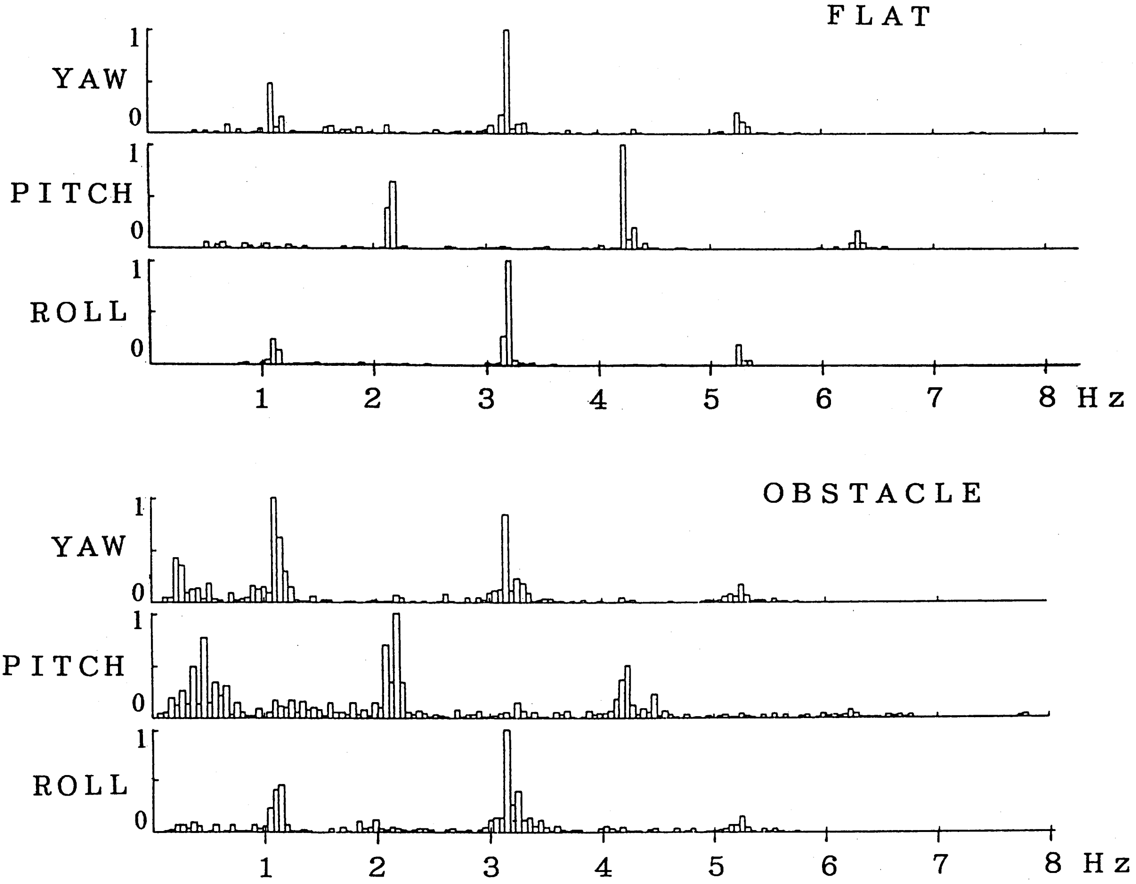

Fig. 4 Results of frequency analysis of head movements with the FFT method (Condition: UPPER, Subject: YM).

Hz, suggesting that head movements are very simple for FLAT but more complex for OBSTACLE. However, the relations of peak frequencies for the three components are similar for FLAT and OBSTACLE. Figure 5 gives mean peak frequencies of head movements for four subjects, demonstrating a tendency for higher frequencies for FLAT than for OBSTACLE. The peak frequency for all conditions ranged from 0.99 to 2.62 Hz.

Analysis of variance

Each of the measurements of head movements was tested with a 2 (walking conditions: FLAT, OBSTACLE) ×5 (visual field conditions: PRE, UPPER, LOWER, RIGHT, CENTRAL) ANOVA for repeated measures. This analysis revealed a significant effect of walking condition in maximum velocity for right ($F(1, 4)=125.76$, $p<.01$) and left ($F(1, 4)=11.4$, $p<.01$) in yawing directions.

DISCUSSION

The above results confirm the remarkable stability of head position during locomotion, especially in normal walking (i.e. task-free with unrestricted visual field). Mean angular velocities for all conditions are similar to those reported by Grossman et al. (1988).

The most unstable head movements observed under restricted visual field conditions were for CENTRAL. The subject could see about 14 degrees of the central visual field only, thus excluding information from the periphery. This confirms the importance of the peripheral visual field in head movements. Because eye movements are limited in this condition, the exaggerated head movements probably compensate for the relative paucity of information available from eye movements. The differences observed between UPPER and LOWER are not well defined, but it seemed that UPPER produces a more unstable head position than LOWER, for both the yaw and pitch components. There are few reports on the functional difference between upper and lower visual fields in humans. More data must be obtained on these two conditions before any meaningful interpretations can be made.

If the hypothesis that there are two types of head movement is tenable, 'searching' head movements must be more effective than 'orienting' movements for OBSTACLE than for FLAT. The head movements for OBSTA-

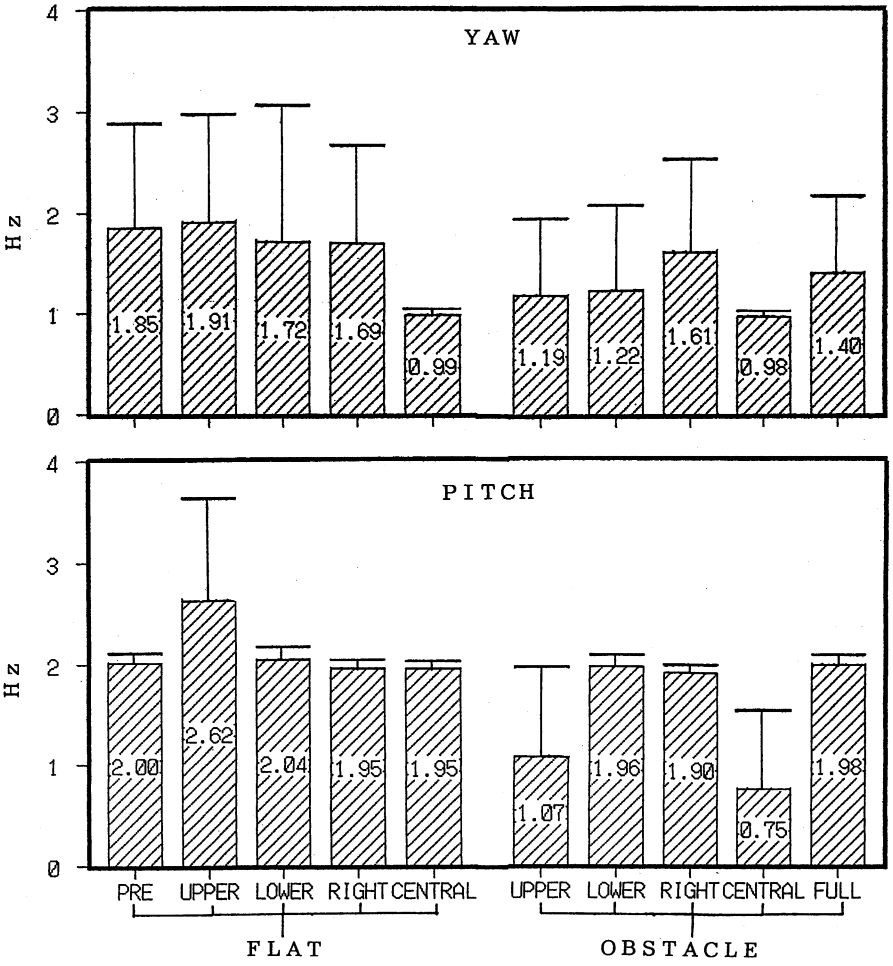

Fig. 5 Mean peak frequencies of angular velocity of head movements (Bars indicate 1 SD).

CLE tended to be larger amplitude movements with a lower peak frequency of angular velocity than for FLAT. It seems reasonable to suppose that there are different strategies for head movements and that the tendency observed for OBSTACLE is a property of the searching strategy. It would be interesting to investigate the mechanism that selects the appropriate strategy.

OBSTACLE condition elicits searching behavior, particularly with CENTRAL. Horikawa (1994) reported that walking speed can be considered as a measure of the effects of visual field restriction. The slowest walking was observed in CENTRAL/OBSTACLE conditions. To navigate around obstacles, the subject presumably estimates the position and distance of obstacles on the corridor floor. The visual field with CENTRAL is narrow, but the subjects could still see the main area of the corridor in the region straight ahead, so intuitively it is expected that, although minimized, the visual input would be sufficient. One possibility to explain the slowness of walking is to consider that the estimation of position and distance requires some kind of calculation which, under restricted visual conditions, is either slowed down by the lack of data or causes an increasing work load on brain activity. Other possible considerations includes the influence of psychological factors.

The process of integrating vestibular and visual information is a central factor in bringing about the stability of head position during locomotion, and eye-head coordination is another important consideration. However, investigation of these complex processes requires the multi dimensional measurement of eye and head movement under unrestricted locomotive conditions. It will therefore be necessary to develop more convenient and precise measuring systems for human body movements during locomotion before this can be achieved.

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