Dynamic and static subjective visual vertical with aging

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Abstract

Objective: Our vestibular function is gradually deteriorating during aging, although, its behavioral consequences are not easily recognized due to a substitution process by other sensory modalities as visual or proprioceptive inputs. Methods: To reveal such a hidden substitution process by visual signals, the measurement of the static as well as the dynamic subjective visual vertical (SVV) was performed among 63 healthy subjects of different age. Results: The static SVV was found to be stable among all subjects, whereas the shift of the dynamic SVV during rotation of a background scene gradually increased with age. Conclusion: This result indicates that the substitution process identified as a function of age in a perceptual test may have its counterpart in postural stabilizing reflex.

Keywords: Vestibular; Subjective visual vertical; Aging; Substitution

1. Introduction

For maintaining the postural stability an integration of vestibular, visual and proprioceptive inputs is required. In order to integrate the signals from the different modalities these inputs have to converge at different levels of the central nervous system, thereby being processed as motor command signals for postural stabilizing reflexes. The contribution of the different sensory modalities to postural stabilization is modified with age as reported for proprioceptive inputs [1]. Moreover, in the vestibular system age related changes were demonstrated anatomically [2] and physiologically [3–5]. Therefore, it is likely that the visual influence on the inertial vertical could be changed as well. After rotation of the peripheral visual field the observer experiences a sensation of apparent self-motion in general and roll vection in particular, when the rotation is parallel to the observer’s roll plane [6]. The measurement of the subjective visual vertical (SVV) shows that the SVV is tilted during roll vection in the direction of the rotation in a stationary observer. The dynamic visual vertical actually reflects a process of substitution of vestibular signals by visual signals [7]. As indicated during space flights the relative contribution of the visual input was enhanced profoundly in microgravity [8], demonstrating a plasticity in the contribution of the different sensory modalities to the determination of the SVV. Similarly, a reduction of vestibular inputs due to an age related impairment should result in an increased visual dependency of the SVV as well. Therefore, the present study was performed to look for an age related plasticity in the contribution of the visual system to the determination of the static and dynamic SVV.

2. Subjects and method

We examined 63 healthy subjects (35 males, 28 females; age range from 21 to 63 years, mean ± S.D. = 39.8 ± 12.2 years). None of them had a history of peripheral or central vestibular disorders. Their neuro-ophthalmological and neuro-otological examinations were normal. All subjects gave their informed consent to participate in the study according to the guidelines of...
the ethics committee of Keio University Hospital. The SVV was measured as a psychophysiological variable for the perceived verticality in a static and a dynamic condition. The subjects sat with their head fixed in the upright position and looked binocularly into a hemispherical dome whose inner surface was covered with a random dot pattern (Fig. 1). This dome (60 cm in diameter) could be rotated around the visual axis of the subject. A small round clear plastic board (10 cm diameter) with an illuminated bar (1 x 10 cm) was attached to the center of the rotation at a distance of 30 cm from the subject so that the subject could adjust the illuminated bar to its subjective vertical using a potentiometer. The static SVV was determined as the average of six consecutive adjustments of the illuminated bar from a random offset position to the subjective vertical with the dome being stationary. The SVV was denoted with a positive value when the tilt was counter clockwise (CCW) and negative when clockwise (CW) from the subject. The dynamic SVV was determined as the average of six consecutive adjustments of the bar from a random offset position to the subjective vertical while the background hemisphere was rotating either CW or CCW with 30° per s. The starting offset of the bar was set alternating at CW or CCW locations between consecutive trials and deviated more than 10° from the vertical position. All subjects experienced a rapidly increasing tilt of the illuminated bar in the direction opposite to the rotation of the hemisphere. The tilt reached its steady state after 3–20 s in different subjects. The dynamic SVV was determined in each subject after a steady state was reached. Statistical analysis was performed with a commercially available computer software (Microcal Origin; Northampton, MA). Linear regression lines of the shifts in the SVV to CW and CCW rotation with respect to age were fitted according to the least square method.

3. Results

The static SVV was close to the objective vertical (0.11 ±0.14 degree; n = 63), fairly stable and independent of the age of the investigated subjects (static in Fig. 2). In the measurements of the dynamic SVV a systematic increase of the shift of the SVV was observed with increasing age of the subjects for rotation in either direction (CW and CCW in Fig. 2). The shift of the SVV increased significantly with age for either direction of rotation (P < 0.001). The change in the shift in SVV with respect to the age of the subjects was symmetrical for both directions of rotation and averaged to −0.30±0.05° per year ($r^2 = 0.36$) for CW and to 0.26±0.05° per year ($r^2 = 0.34$) for CCW rotation. The small difference in the absolute value of the slope was statistically not significant. This symmetry between CW and CCW originated from a symmetry of the shift in a given subject. This is indicated by the small difference between

![Fig. 1. The equipment for the measuring the SVV both in static and dynamic condition is shown in the photograph.](image1)

![Fig. 2. Age dependent correlation of the static and dynamic SVV in 63 healthy subjects. The dynamic SVV was examined by clockwise (CW) and CCW rotation of a background hemisphere at a stimulus speed of 30° per s. Note, that the static SVV is stable among all subjects, while the shift of the dynamic SVV increased significantly (P ≤ 0.001) with age for CW and CCW rotations, respectively. Regression lines were fitted according to the least squares method ($r^2 = 0.36$ for CW rotation; $r^2 = 0.34$ for CCW rotation); positive values indicate CCW deviation; negative values indicate CW deviation.](image2)
the absolute values of CW and CCW shifts for individual subjects \((0.13 \pm 3.28^\circ; \ n = 63)\). In order to compare our data with existing data in the literature [7,9] the values of all subjects were pooled for CW and CCW rotations. Following this analysis the mean tilt of the SVV was \(-8.60 \pm 6.70^\circ\) for CW rotation and \(8.71 \pm 6.27^\circ\) for CCW rotation \((n = 63)\) at a constant stimulus speed of \(30^\circ\) per s.

4. Discussion

In contrast to the static SVV, which was similar in magnitude among all subjects, a gradual increase with age of the shift of the dynamic SVV during rotation was observed. The increase in shift was similar for rotations to both sides indicating a symmetrical effect. We suppose increase relative contribution of visual input during aging as an explanation to these results. Bronstein et al. have already reported such an age related shift in tilt of the SVV from 24 normal subjects \((\text{age } 50 \pm 18)\) [7]. In their study, however the number of subjects was relatively small. In addition, the detailed description and interpretation of individual data was not presented. Tilt of the SVV in their study was \(-16.17 \pm 6.86\) (CW rotation), and \(15.37 \pm 7.61\) (CCW rotation), both of which are larger than our data [7]. Older age in their subjects population and minor difference in the measurement equipment might have contributed to these differences. On the other hand, an increase of the neck proprioceptive input with age has been reported by Strupp et al. [1] after measuring the subjective visual straight-ahead with a neck vibration stimulation. They correlated their functional observations with the reported progressive declination of the vestibular nerve fibers [8]. In addition, other age related structural changes i.e. progressive declination of the macular otoconia [9], vestibular ganglion cells [10] and labyrinthine hair cells [11] were reported as structural sources of an age related functional impairment of the vestibular system. A deterioration of the equilibrium score and VOR gain was shown during aging that was correlated with a progressive bilateral peripheral vestibulopathy [12].

Further supporting evidence for an increase in the contribution of visual signals and a decrease of vestibular signals to postural control comes from elderly fallers who tend to rely more on visual cues [13]. Lord et al. [13] reported in elderly subjects that a test of the roll vection was a better discriminator between fallers and non-fallers than the rod and frame test. Among elderly subjects fallers tend to have a larger error in perception of the subjective vertical than non-fallers indicating again an increased contribution of visual signals in those subjects with impaired vestibular signals. Furthermore, it shows that a significant difference of a shift in perception from the objective vertical can be better recognized with a dynamic than with a static test.

Such a plasticity in the contribution of the different sensory modalities to postural stabilizing reflexes not only occur during aging but can also be seen in the subjects with vestibular dysfunction. For example, dramatic plasticity was seen in patients with a bilateral vestibular dysfunction. These patients with a profound bilateral vestibular loss experienced a completely unambiguous self-motion when exposed to vection about the pitch or roll axes [14]. This suggest that in the absence of any signals from otolithic organs, a static somatosensory input alone is not sufficient to compensate for the effects of a dynamic visual stimulation. The dynamic visual vertical actually reflects a process of substitution of vestibular signals by visual signals, since patients with absent vestibular function showed larger SVV tilts during roll vection [7]. The fact that subjects with a higher vestibular threshold have lower vection onset latency [15] is compatible with the idea that the contribution of visual signals is enhanced in subjects with a reduced contribution of vestibular signals. Finally, the notion that visual inputs may substitute for otolith inputs is supported by the findings from animal experiments where otolith sensitive units in the cat’s vestibular nucleus responded to visual stimulation and also to translational movement of a large visual field [16].

5. Conclusion

A measurement of the dynamic SVV with a relatively slow angular velocity rotation of the background scene resulted in an increasing shift of the visual vertical from the objective visual vertical with the age of the subjects. The substitution process identified as a function of age in a perceptual test may have its counterpart in postural stabilizing reflex. Such an apparent substitution facilitates maintaining balance and most likely originates in a general plasticity that shifts the relative contribution of each of the converging signals according to changes in the activity of peripheral sensory inputs. However, since the dynamics of the different sensory systems differ from each other, a complete substitution of one sensory input by another is not possible and therefore must remain only partial.

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