Environmental Medicine, 47, 2003 (page 85 ~ 89)

Characteristic Changes of Sway of Center of Gravity with Advancing Age

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Abstract: The righting reflex to avoid falls is altered with advancing age. The purpose of the present study is to find a good index for representing how the righting reflex is exacerbated with advancing age. We carried out stabilometry for standing subjects who were healthy adults with age <51 (9M & 11F, younger group) and ≥51 (22M & 8F, elderly group). The stabilometry required the subjects to stand on a stabilometer with fixing their eyes to the screen (1 min) and their eyes closed (the following 1 min). Statokinesigrams resulting from the stabilometry were analyzed by 8 indices. In the "Eyes opened" state, significant changes in previous indices were not found by a decline in the equilibrial function with advancing age. Our proposed index, a total of local sums of forces on chains I, was regarded as the most robust and appropriate index to statokinesigrams for the "Eyes opened/closed" state. This index was applied to the simulation of the elderly (pseudo-elderly study); the subjects were healthy adults with age of 19–29 (5M & 19F) and wore apparatuses as glasses, earplugs, and weights in the stabilometry. These indices obtained from the statokinesigrams indicated that pseudo-elderly group was the most stable, and the elderly group was the least.

Key words: Aging, Righting reflex, Sway of the center-of-gravity of the body, Statokinesigram, and A total of local sums of forces on chains

Introduction

The standing posture of the human is maintained by the function of the body's balance function, which is an involuntary physiological adjustment mechanism (Okawa et al. 1995), namely "righting reflex". The evaluation of this function is indispensable for diagnosing patients with equilibrium disturbances, e.g. cerebellar degenerations, basal ganglia disorders, or Parkinson's disease (Okawa et al. 1996). To evaluate this equilibrial function qualitatively and quantitatively, stabilometry has been employed, and a projection of a subject's center of gravity onto a detection-stand are traced for each time step. The time series of the projections traced on a xy-plane is called a statokinesigram (resulting from the stabilometry). Analysis of the statokinesigrams is useful not only for medical diagnosis but also for elucidation of control for upright standing by two-leg robots, and for preventing the falls in the elderly (Fujiwara et al. 1993).

Aging exacerbates the eyesights, auditory and vestibular functions, proprioceptive inputs from skin, muscles, and joints (Goto 1992; Sato 1993). The information from these sensory receptors are attenuated with advancing age (Diener & Dichgan 1988). It has been already postulated that the instability is developed with advancing age, however, what elements is responsible for the falls in the elderly has not been elucidated so far (Sato 1993). In order to maintain the standing postures without their locomotion, the righting reflex is inevitable, which is centered in the nucleus rubber (Kaga 1992). Recent aging studies measured subjects who wore glasses, earplugs, and weights (Fig. 1). Comparison of the equilibrial function of these pseudo-elderly subjects to the actual elderly group without apparatus should also be examined.

Several parameters have been proposed to quantitize the instability by stabilometry, 1)–3) listed in Table 1 by Suzuki et al. (1996) and they are widely used for clinical studies (Tokita 1995). However, it is not difficult to diagnose disorders of the sense of the equilibrium and identify declines in the equilibrial function clinically with previous indices for stabilometry. Large interindividual difference made understanding of the results difficult in the comparison of statokinesigrams for young to elderly subjects (Yoneda & Tokumatsu 1987).

In addition to the above parameters 1)–3), we herein analyze our new indices 4)–8) for each statokinesigram as

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This work was supported by Grants-in Space Forum, Japan.

Table 1 **Averages and standard deviations of indices for statokinesigrams for every group and state** (Average ± Standard Deviation). With the use of some index, the averages of the younger group were different from those of the other group with statistical significance ($p<0.05$*, $p<0.01$**).

State		Eyes Opened			Eyes Closed		
Groups		Younger	Elderly	Pseudo-Elderly	Younger	Elderly	Pseudo-Elderly
1)	Area of sway	2.17 ±0.84	4.43 ±2.64	1.52 ±0.73**	2.23 ±1.03	5.65 ±4.00	1.36 ±0.54**
2)	Total locus length	56.21 ±9.20	97.94 ±25.09	52.41 ±13.80**	67.51 ±19.90	141.50 ±60.19**	51.31 ±11.58**
3)	Locus length per unit area	29.86 ±12.80	26.64 ±1.91	41.46 ±19.42**	34.03 ±11.74	29.94 ±10.59	42.30 ±15.56
4)	Sparse density	1.91 ±0.28	4.10 ±1.91	1.73 ±0.30**	1.91 ±0.28	4.80 ±2.96	1.73 ±0.30**
5)	Total locus length of the chains I	1.84 ±0.83	7.60 ±2.36*	1.45 ±0.91**	2.87 ±1.65	9.78 ±3.46*	1.77 ±0.99**
6)	A total of local sums of force on the chains I	1.82 ±0.96	12.18 ±4.23*	1.17 ±0.91**	2.97 ±2.29	17.37 ±8.55*	1.35 ±0.86**
7)	Total locus length of the chains II	1.06 ±0.22	2.04 ±1.05	0.98 ±0.28**	1.27 ±0.41	2.95 ±1.91**	0.92 ±0.21**
8)	A total of local sums of force on the chains II	20.35 ±5.30	56.28 ±27.38	0.06 ±0.03**	26.29 ±11.49	103.27 ±132.14*	16.93 ±4.22**

indicated in Table 1. In the present study, we examine how our proposed indices 4)–8) for statokinesigrams are altered with advancing age by comparing the results from the young and the elderly, as well as the pseudo-elderly groups. We verify whether variations of these new indices are estimated at lower values than those of the previous indices.

Methods

Subjects stood quietly on a detection stand of the stabilometer (Kistler Instruments, Switzerland) with the Romberg posture with their feet together for 1 min before the recording of the sway. The sway of each center of gravity was then recorded (sampling frequency 20 Hz). The data from the stabilometer was amplified with the definition of 2 mm. They then stood with their eyes opened (1 min) and closed (the following 1 min) with visual stimulation by a view from very high place on the top of a roller coaster track, which was given by a video projector on an 80-inch silver screen with a distance of 3 m.

Subjects were healthy volunteers with three groups; Young group with age >51 (9M, 11F), Elderly group with age ≥51 (22M, 8F), and Pseudo-elderly group aged 19–29 yrs. (5M, 19F) with simulation apparatus of aged people (Fig. 1).

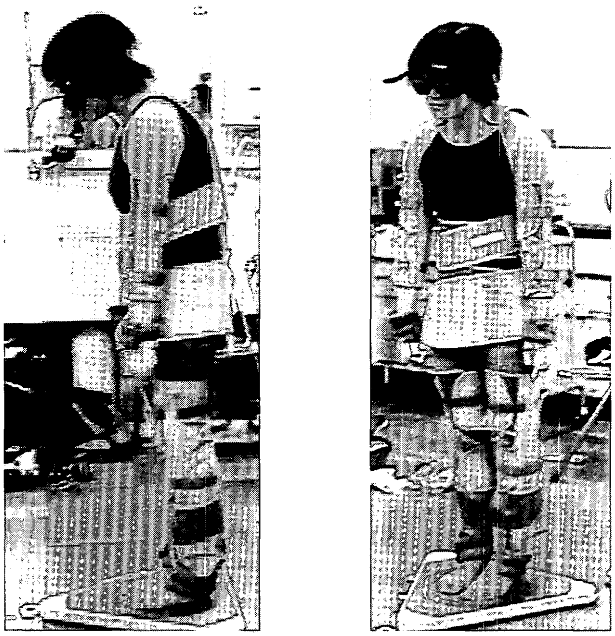

Fig. 1 **Special suit to simulate the elderly.** Special suit consists of glasses of narrow visual fields with poor eyesights, earplugs to decline hearing ability, and weight loads to reduce the performance, namely pseudo-elderly.

Here, our proposed new indices are defined; the Sparse density was introduced to the stabilometry by Takada & Kitaoka et al. (2003), which was defined by a scaling average of the ratio as $G_j(1)/G_j(k)$. Here, a statokinesigram was divided into quadrates of which the latus is j times longer than that of the resolution and $G_j(k)$ expressed the amount of divisions including more than k measured points. To include a consideration of the physical meaning of the sparse density, the *force* acting on the center-of-gravity of the body was defined by a difference in displacement vectors (Takada & Omori et al. 2003). We especially turned our attention to singular points where statistically tiny or huge forces were exerted. On the basis of the force, the chains were cut away from a statokinesigram as consecutive time series respectively. If the times measured these points were temporally vicinal, these points were connected by segments (sequences). The figures of these sequences were named as chains after their connecting shape. "Chain I" (Fig. 2.1) was defined by the figures of the sequences of points where tiny forces were excreted, and "chain II" (Fig. 2.2) was defined by those of points where huge forces were (Takada & Omori et al. 2003).

In order to compare the Younger group with the other group, statokinesigrams were evaluated by the eight indices listed in Table 1, and the Welch test was employed. We examined significant changes in these indices with advancing age (Shimizu & Takada 2001). In both statistical tests, $p<0.05$ was considered significant.

Results

The difference between young and pseudo-elderly group was not so apparent in the statokinesigrams (Sato 1993), however, the patterns of statokinesigrams from the actual elderly subjects were clearly different from those from young and pseudo-elderly groups because the scatter diagrams were highly diffused. Actually, we often extracted extremely long chains from subjects of highly advanced age in the elderly group (Fig. 3).

The eight indices calculated from statokinesigrams were shown in Table 1. The lowest averages of the indices resulted from statokinesigrams of the pseudo-elderly subjects except for the locus length per unit area. For every state, the mean values of the total locus length of the chains I and the total of local sums of forces on the chains I, which we proposed as new indices, for the young group were significantly different from those for the elderly and for the pseudo-elderly by the Welch test (Table 1).

Almost all the indices tended to increase with advancing age. The slopes for subject's "eyes opened" state were more gradual than those for subject's "eyes closed" state (Fig. 4). Thus, there were not significant correlations between age and indices for every state, except for the total of local sums of forces on chains I ($t = 2.43$ in the "eyes opened" state, $t = 2.68$ in the "eyes closed" state, $p<0.05$).

Discussion

Chains I indicate local fluctuations or straight lines, and chains II depict a cusp formed pattern (Figs. 2). The control of the center-of-gravity of the human body might be expressed as our proposed geometrical pattern. As seen in Table1, the indices corresponding to chains I were useful for indicating a decline in the equilibrial function with advancing age. Chains I contain high frequency fluctuation which is considered to be

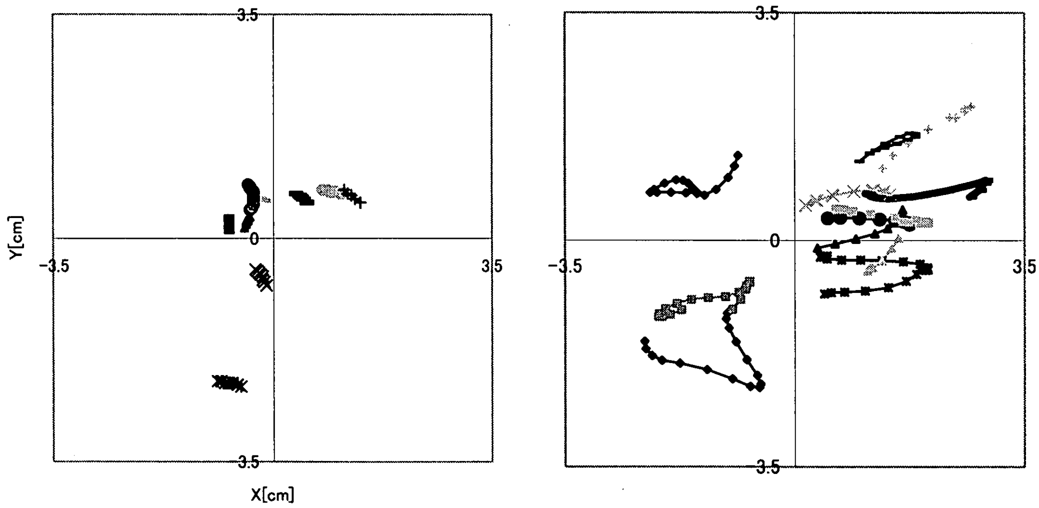

Fig. 2 **Chains I (Fig. 2.1) and chains II (Fig. 2.2).** The center-of-gravity were taken in consecutive time steps as t, $t+1$, $t+2$.... Points measured at time t and the vicinal time as $t-2$, $t-1$, $t+1$, and $t+2$ were extracted because the local sum of force defined by the forces acting on the center-of-gravity at these times, and were scatted on a plane. These figures were shown to define the chains by Takada & Omori et al. (2003).

stable locally (Takada et al. 2001; Takada & Kitaoka et al. 2003) although the motion has been analyzed by the locus length per unit area (Okawa et al. 1995). Moreover, we traced the effects of aging in eight indices for the statokinesigram. Only the total of local sums of forces on chains I could demonstrate a decline of the equilibrial function with advancing age (Fig. 4). Especially, the figures for "eyes opened" state showed large interindividual differences in the elderly (≥50 years) subjects. Thus, we suggest that visual information is still effective in the equilibrial function of elderly subjects.

The statokinesigrams in the elderly were derived from different standing postures or systems to control the sway of the elderly from the younger subjects. The characteristic chains (Fig. 3) were generated by the delay in counteracting forces resulting from the righting reflex to maintain their standing postures. The elderly subjects might take more time when their center of gravity is far from the ideal center in the process of falling down (sensing error). Thus, chains I were considered to be optimal for detecting the righting reflex.

Alcoholic load causes a decrease in the cerebellar equilibrial function controlling vestibulo-spinal reflex (Kaga 1992). The sparse density was stable and useful for measuring density in local areas on scatter diagrams and could indicate a decline in the equilibrial function with the alcoholic load (Takada & Kitaoka et al. 2003) although it could not detect the righting reflex with advancing age.

The present study also demonstrated that the apparatus to simulate the elderly physical function could not produce the instability seen in the actual elderly subjects.

Thus, total locus length of chains I, and the total of local sums of forces on chains I could be good indices for stability. Measurements of these parameters in a large population for every age group should be projected in future studies in order to make a good index for standing stability. Prevention of falls in the elderly using this index as a risk factor would be a next step.

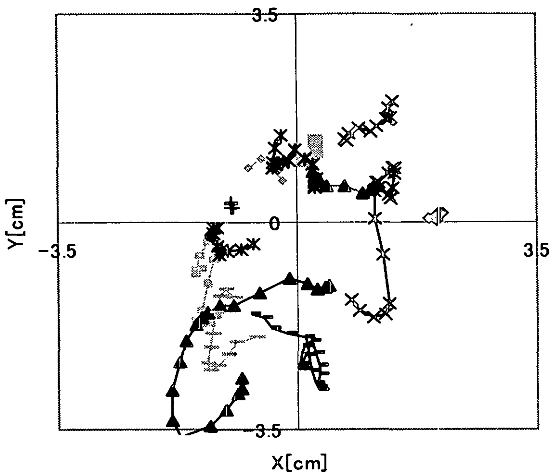

Fig. 3 **Characteristic chains.** These chains II were extracted from a statokinesigram for elder persons. This typical figure shows characteristic chains that consist of points observed for several seconds.

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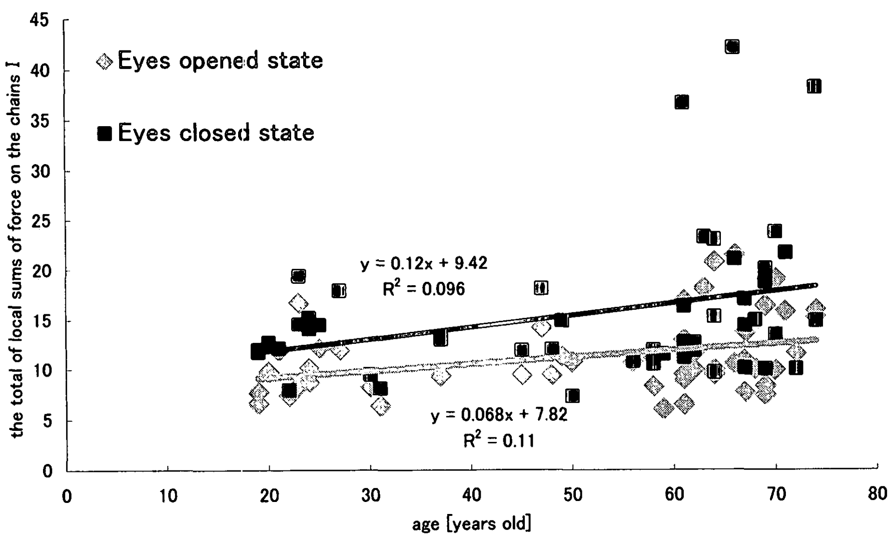

Fig. 4 **Typical variations in the index for statokinesigrams with aging.** This figure depicts the values of the total of local sums of force on the chains I for every state.

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Received June 19, 2003; accepted July 24, 2003