

Original Paper

Study on Vision and Static Physical Balance Function Report 1: Healthy Young and Middle-elder People

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Abstract

The purposes of this study were to examine static physical balance function in healthy people and determine standard values. Postural position and target sway were measured under the three conditions of eyes open (EO), eyes closed (EC), and visual feedback (VF). These were carried out in the standing posture using the Balance Master physical balance function measurement device in 24 healthy young people (mean age 21.0 years) and 20 healthy middle-elder people (54.1 years). Postural position and target sway exhibited the same values in young and middle-elder subjects in the EO condition. Target sway in middle-elder subjects was significantly larger under EC ($P < 0.05$). In the EC condition, postural position was more forward-inclined in middle-elder subjects than in young subjects. In the VF condition, there was no deviation in postural position in young subjects, but there was significant forward inclination in middle-elder subjects ($P < 0.05$). Physical balance function is closely related to visual input. When young and middle-elder subjects were compared, postural position shifted in the forward direction and target sway tended to increase with aging. It is suggested that the balance mechanism changes with aging, and in particular, balance adjusting functions other than the visual system regress markedly.

1. Introduction

Various information from the visual system plays an important role in a person's ability to maintain a standing posture. It has been shown that body sway characteristics vary depending on the quantity and nature of visual information, and that visual impairment amplifies body sway [1-10]. There have been numerous reports on physical balance function (PBF) in relation to visual disorders such as monocular and binocular vision [11], ocular deviation [9, 12, 13], ocular dominance and binocular function [14], visual impairment [6], abnormal visual field [4], cataract [5, 7, 15], glaucoma [8] and age-related macular degeneration [16]. Body sway in the standing posture has been used as an indicator of static PBF, and it has been reported that body sway increases with age [4, 17-19]. On the other hand, it has also been reported that there was no significant difference in body sway between elderly and young people when simply upright standing with eyes either open or closed [20-22].

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Subjects in the study of Hageman et al. [19] were young people aged 20-35 and middle-elder people aged 60-75. PBF changes largely with age, so it requires that comparison data of healthy people must be the same age as that of the subjects. Also, numerical data in analysis items differs according to conditions in facilities and used equipment. In this study, we aimed to acquire data of PBF in acquired ocular movement disorder (AOMD), matching the age of subjects and considering data of healthy people as standards.

2. Subjects and methods

2.1. Subjects

The study population consisted of 44 healthy people. The young subjects consisted of 24 subjects (aged 19 to 23, mean age \pm standard deviation (SD) 21.0 ± 1.1 years). The middle-elder subjects consisted of 20 subjects (aged 41 to 65, 54.1 ± 7.1 years). The 1998 White Paper on the National Lifestyle published by the Cabinet Office of Japan (formerly the Economic Planning Agency) defines middle age as ages 40 to 59 [23]. Thus, in this study, subjects under 40 years of age were classified as young, and subjects 40 years and older were classified as middle-elder. In all subjects, there was no history or current subjective symptoms of eye disease, visual acuity was 1.0 or more in both eyes, binocular function according to Titmus stereo tests was normal at less than 60 seconds of **arc**, eye position was orthophoria or heterophoria, and there was no history of vertigo.

2.2. Methods

2.2.1. Measurement device and measurement principle

PBF was measured using the Balance Master MPS-1102 (NeuroCom[®] International Inc., USA) (Fig. 1). The

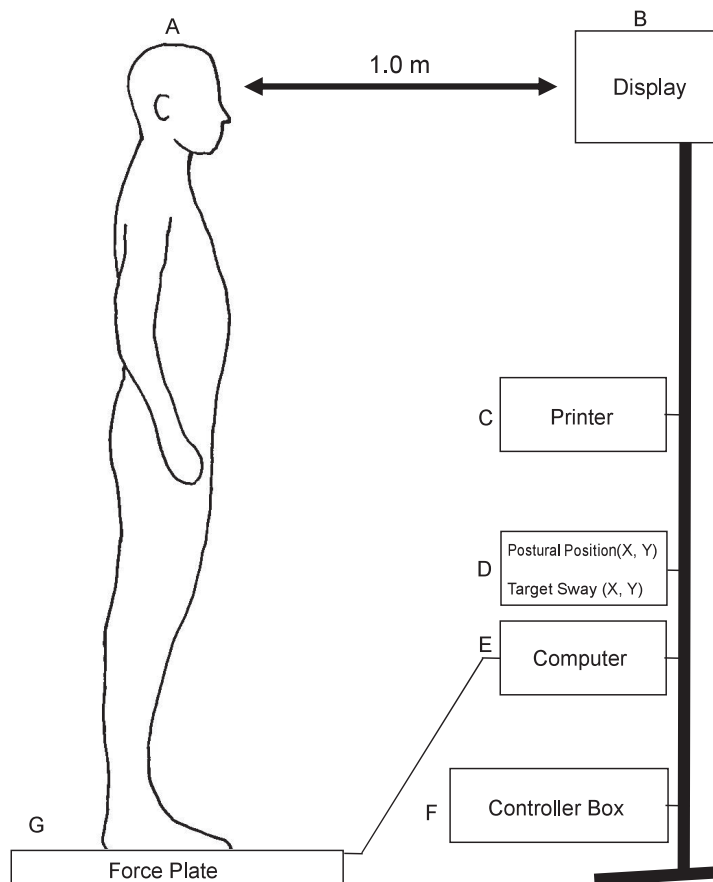


Fig. 1 Physical balance function measurement device

A: Subject, B: Display, C: Printer, D: Postural Position (X, Y), Target Sway (X, Y), E: Computer, F: Controller Box, G: Force Plate.

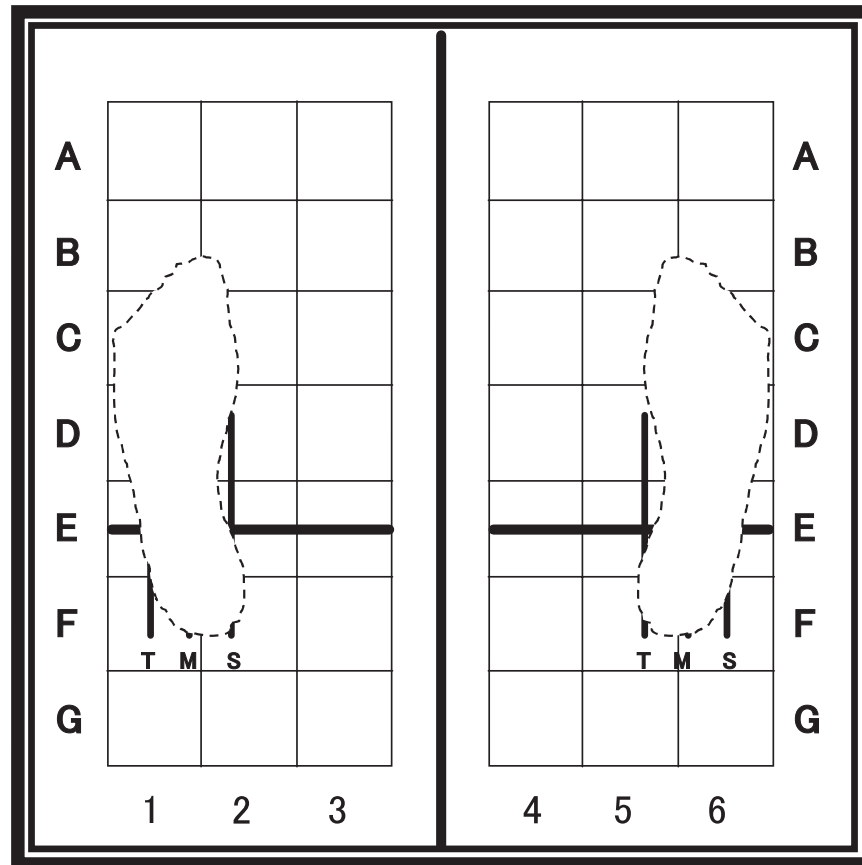


Fig. 2 Sole guides

Subject stands in standing-at-ease posture on the platform of the Balance Master with the lateral malleolus aligned with the intersection of E and the position determined by the subject's height (S: 76-140 cm, M: 141-165 cm, T: 166-203 cm).

subject stepped on a force plate (Fig. 2) measuring 48.5 cm long by 48.5 cm wide by 5.5 cm high attached to the main device, with the lateral malleolus of each foot aligned with line E and the outside of the heel aligned with one of three foot-width positions specified according to subject height (76-140 cm = S, 141-165 cm = M, 166-203 cm = T). The base of the force plate was equipped with two sets of pressure sensors in the X direction and two sets in the Y direction. The theoretical postural position was displayed as the intersection of the X and Y axes at the center of a 13-inch cathode-ray tube (CRT) screen placed 1 m in front of the subject at the same height as the median line between the eyes calculated from the difference in pressure displacement applied to the force plate from the soles of the subject's feet. The case where the actual postural position (P.P.; units: %limit of stability (%LOS), degree (deg.)) of the subject was forward of the theoretical PP was displayed on the Y axis (positive), backward was displayed on the Y axis (negative), rightward was displayed on the X axis (positive), and leftward was displayed on the X axis (negative) (Fig. 3). This device was a clinical gravicorder capable of measuring static and dynamic PBF. Because the examination was completely non-invasive, it did not require the subject to wear a device and places no burden on the subject. Also, it had the advantage of measurement that was possible across a wide range of subjects from young to elderly [24-26].

2.2.2. Static PBF measurement method

This measurement determined PP and target sway (T.S.; units: %maximum area (%MA)) in the standing posture with the upper arms naturally falling down in contact with the sides of the body.

Three measurement conditions were used: (1) EO condition, in which both eyes were open, looking

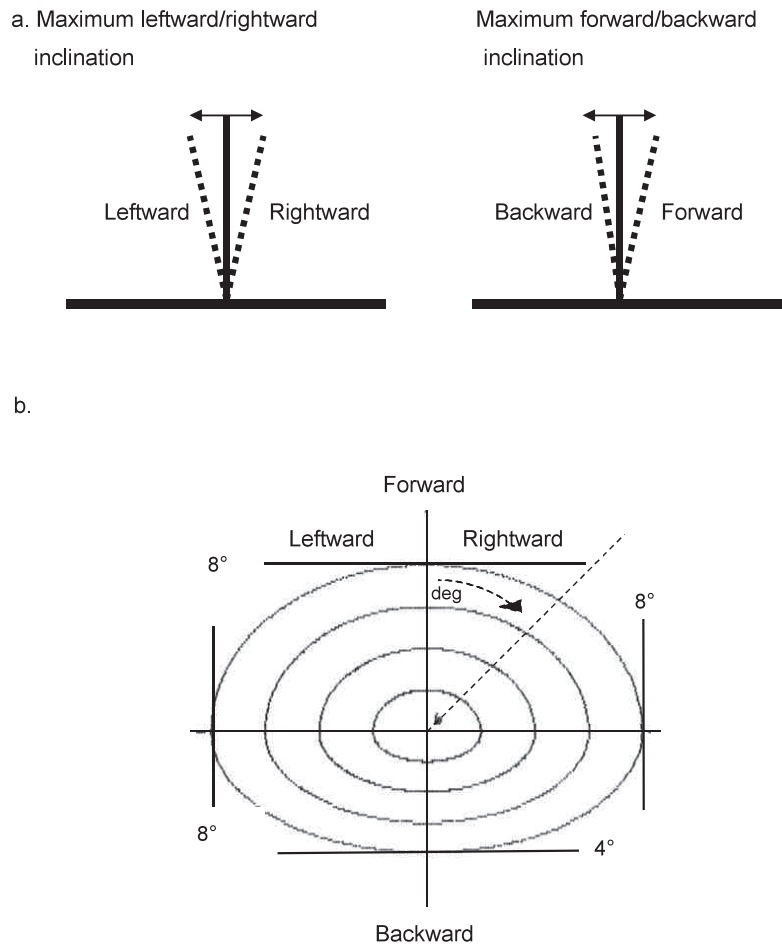


Fig. 3 Schematic diagram of postural positions

a. Maximum inclination angles: Forward 8° ; Backward 4° ; Left/Right 8° each.

b. Coordinates of mean postural position. Degrees (deg) indicate the postural position from 0° to 360° .

straight at a CRT screen that did not present a solid visual target (no target, eyes open); (2) EC condition, in which both eyes were closed (no target, eyes closed); (3) VF condition, in which the subject's own PP represented by a human figure measuring 9 mm high by 9 mm wide (visual angle: 0.52°) was aligned within a solid visual target having an inside diameter of 12 mm high by 12 mm wide (visual angle: 0.69°) displayed at the intersection of the X and Y axes at the center of the CRT screen (target, visual feedback). The measurement time in each condition was 20 seconds.

2.2.3. Postural position (PP) measurement

The intersection of the X and Y axes on the force plate was defined as the subject's theoretical PP (0%), and the limits of stability (LOS) of PP at the maximum inclination angle of the body to the front, back, left and right calculated from subject height were defined as 100% . According to the definition of Hamman et al. [24], the limit of the center of gravity at the body inclination angle at which a person would maintain the standing posture without falling over was the "limit of stability of standing posture." The inclination angle of the limit of stability of standing posture was measured at the maximum forward inclination (8 degrees), maximum backward inclination (4 degrees), and maximum leftward and rightward inclinations (8 degrees each) [27]. Taking the PP at the maximum forward inclination and maximum backward inclination of each subject as 100% and taking the center of foot pressure as 0% , the PP of a subject in the standing posture on the force plate was taken as the radial distance from the center for the relative value of center of gravity

(%LOS) [24, 28]. The directional position (deg) of a subject's center of gravity was expressed on a coordinate system as 0 degrees (360 degrees) for the direction straight ahead, from 0 to 90 degrees for right-front directions, 90 to 180 degrees for right-back directions, 180 to 270 degrees for left-back directions, and 270 to 360 (0) degrees for left-front directions .

2.2.4. Target sway (TS)

TS expressed a subject's range of TS as a proportion (%MA) of a subject's maximum sway area (MA). If PP did not sway at all, it was taken as 0%, and if PP sways from the center position to the maximum inclination position, it was taken as 100%. The fine swaying of the body so that it did not fall over was recorded as a trace of the center of foot pressure as the vertical center of gravity along the long axis of the body. Thus, TS, which constituted the balance control function when standing up, was captured in two-dimensional coordinates by an electrogravitiogram.

2.2.5. Romberg ratio

The Romberg ratio, which serves as an index of the contribution of vision to balance when in standing posture, was determined as the ratio of target sway in the EC condition to target sway in the EO condition [29].

2.2.6. Statistical processing

After checking for homogeneity of variance using Bartlett's test, testing was performed using parametric one-factor ANOVAs and Wilcoxon signed rank sum tests. For all tests, a difference with a significance level less than 5% was considered significant.

2.2.7. Ethical considerations

In conducting this study, the cooperation of study subjects was sought after providing them explanations of the nature of the study and ethical considerations. This study was approved by the Ethics Committee of the Kawasaki University of Medical Welfare (approval no. 14-003) and conformed to the tenets of the Declaration of Helsinki.

3. Results

3.1. PP and TS in healthy young subjects

Table 1 showed mean \pm SD of PP and TS in the EO, EC and VF conditions in 24 healthy young subjects. The results are discussed for each condition separately (Fig. 4).

Table 1 Postural position and target sway in healthy young subjects

	n	EO	EC	VF
Postural Position (%LOS)	24	9.30 \pm 15.84 R = 1.42 \pm 1.02	7.36 \pm 17.67	-0.03 \pm 1.16
Target Sway (%MA)	24	0.01 \pm 0.08 R = 1.42 \pm 1.11	0.01 \pm 0.08	0.01 \pm 0.05

n: numbers, EO: Eyes Open, EC: Eyes Closed, VF: Visual Feedback, %LOS: %Limits of Stability, %MA: %Max Area, R: Romberg Ratio. Values show mean \pm standard deviation.

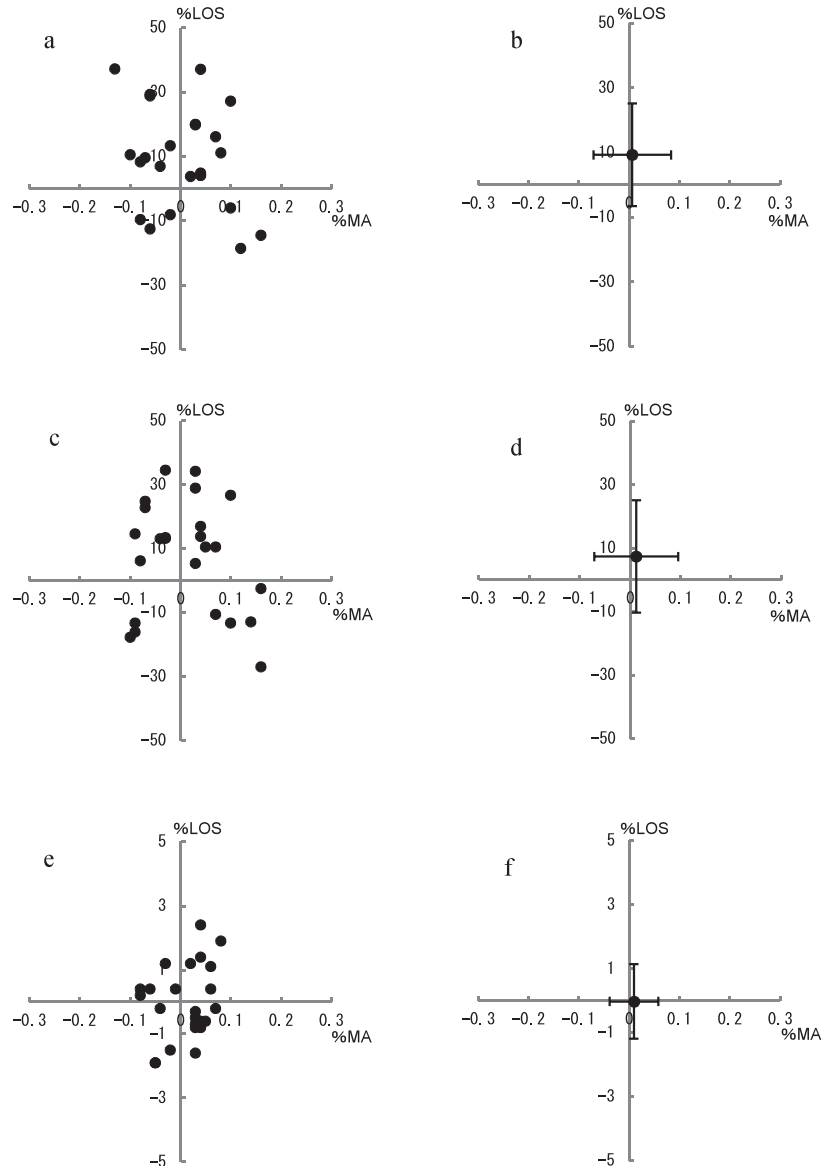


Fig. 4 Postural position and target sway in healthy young subjects

The intersection of the X and Y axes is the theoretical postural position of the subject on the force plate. Vertical axis represents postural position (%LOS), horizontal axis represents target sway (%Max Area: %MA).

- a. Distribution in EO condition, b. Mean \pm SD in EO condition,
 c. Distribution in EC condition, d. Mean \pm SD in EC condition,
 e. Distribution in VF condition, f. Mean \pm SD in VF condition.

3.1.1. PP in the EO condition

In 18 of 24 young subjects, the PP was forward of the theoretical center of gravity; both left and right shifts occurred. Three cases showed PP in the right-back direction. Three of the remaining cases were shifted to the left-back direction. As shown by the mean (SD) PP values in Table 1, the center of gravity was at 9.30% of the forward falling limit value and 0.01% to the right in healthy young subjects in the EO condition.

3.1.2. PP in the EC condition

In 17 of 24 young subjects, PP was forward of the theoretical center of gravity; both left and right shifts

occurred. Five cases showed PP in the right-back direction. Two of the remaining cases were shifted to the left-back direction. As shown by the mean (SD) PP values in Table 1, the center of gravity is at 7.36% of the forward falling limit value and 0.01% to the right in healthy young subjects in the EC condition.

3.1.3. PP in the VF condition

In 11 of 24 young subjects, the PP was forward of the theoretical center of gravity; both left and right shifts occurred. Nine cases showed PP in the right-back direction while four cases showed a PP in the left-back direction. As shown by the mean (SD) PP values in Table 1, the center of gravity is at 0.03% of the backward falling limit value and 0.01% to the right in healthy young subjects in the VF condition.

3.1.4. Romberg ratio of PP and TS

Both of the Romberg ratios of PP and TS in healthy young subjects were 1.42.

3.2. PP and TS in healthy middle-elder subjects

Table 2 showed the mean \pm SD of PP and TS in the EO, EC, and VF conditions in 20 healthy middle-elder subjects. The results are discussed for each condition separately (Fig. 5).

3.2.1. PP in the EO condition

In 19 of 20 middle-elder subjects, the PP was forward of the theoretical center of gravity; both left and right shifts occurred. One case was shifted to the right-back direction. As showed by the mean (SD) PP values in Table 2, the center of gravity was at 17.43% of the forward falling limit value and centered on the X axis in healthy middle-elder subjects in the EO condition.

3.2.2. PP in the EC condition

In 19 of 20 middle-elder subjects, the PP was forward of the theoretical center of gravity; both left and right shifts occurred. One case showed PP in the right-back direction. As shown by the mean (SD) PP values in Table 2, the center of gravity is at 21.78% of the forward falling limit value and 0.04% to the right in healthy middle-elder subjects in the EC condition.

3.2.3. PP in the VF condition

In 18 of 20 middle-elder subjects, the PP was forward of the theoretical center of gravity; both left and right shifts occurred. Two cases showed a PP in the right-back direction. Mean (SD) PP was at 0.93% of the forward falling limit value and 0.02% to the right in healthy middle-elder subjects in the VF condition.

3.2.4. Romberg ratio of PP and TS

In healthy middle-elder subjects, the Romberg ratio of PP was 1.65, and that of the TS was 1.51.

Table 2 Postural position and target sway in healthy middle-elder subjects

	n	EO	EC	VF
Postural Position (%LOS)	20	17.43 \pm 13.32 R = 1.65 \pm 1.56	21.78 \pm 13.36	0.93 \pm 1.41
Target Sway (%MA)	20	0.00 \pm 0.09 R = 1.51 \pm 1.05	0.04 \pm 0.10	0.02 \pm 0.08

n: numbers, EO: Eyes Open, EC: Eyes Closed, VF: Visual Feedback, %LOS: %Limits of Stability, %MA: %Max Area, R: Romberg Ratio. Values show mean \pm standard deviation.

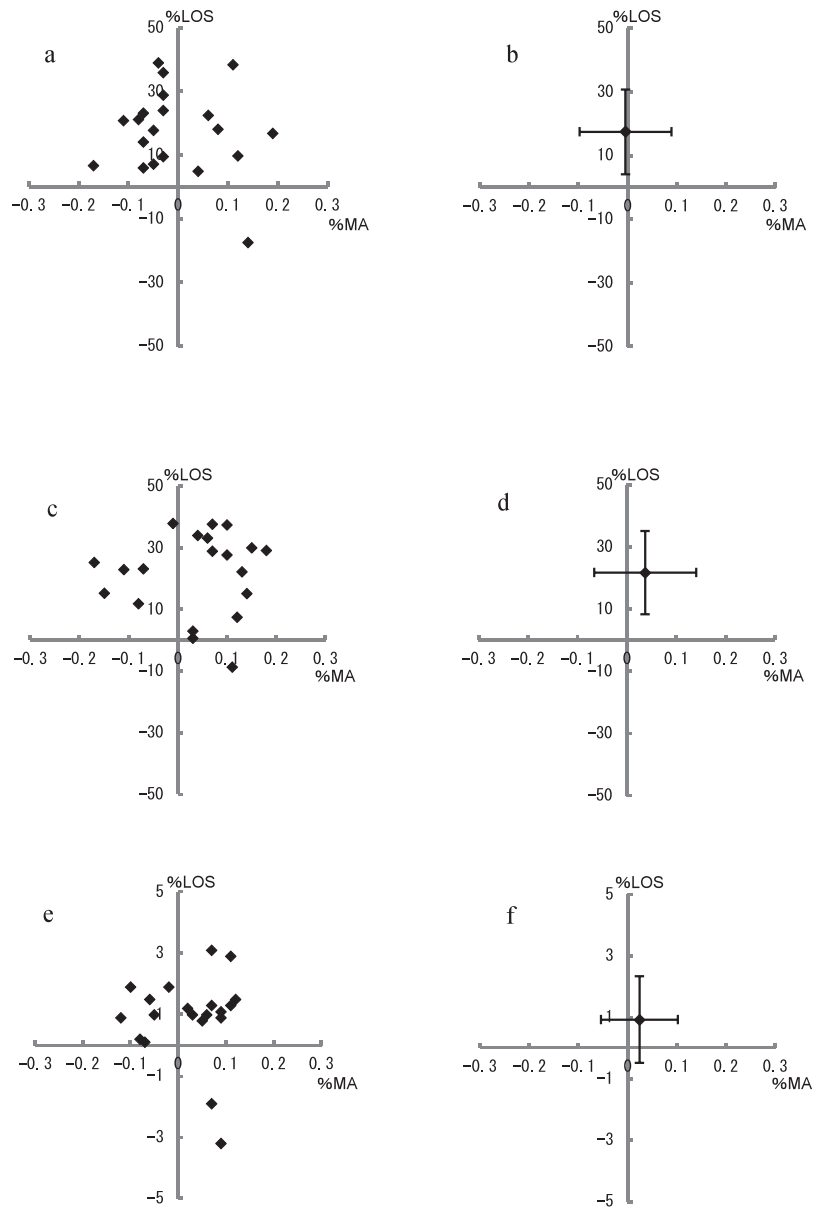


Fig. 5 Postural position and target sway in healthy middle-elder subjects

The intersection of the X and Y axes is the theoretical postural position of the subject on the force plate. Vertical axis represents postural position (%LOS), the horizontal axis represents target sway (%Max Area: %MA).

- a. Distribution in EO condition, b. Mean \pm SD in EO condition,
 c. Distribution in EC condition, d. Mean \pm SD in EC condition,
 e. Distribution in VF condition, f. Mean \pm SD in VF condition.

3.3. Comparison of young and middle-elder subjects for PP and TS

When the mean \pm SD of PP and TS paired in healthy 24 young and 20 middle-elder subjects, there was no significant difference in PP between young and middle-elder subjects in any of the two conditions of EO and EC. However, there were differences in PP between young and middle-elder subjects in the VF condition ($P=0.02$). In any of the two conditions of EO and VF, there was no significant difference in TS between young and middle-elder subjects. However, there were differences in TS between young and middle-elder subjects in the EC condition ($P=0.03$) (Table 3).

Table 3 Comparison of young and middle-elder subjects for postural position and target sway

	Postural Position (%LOS)			Target Sway (%MA)		
	EO	EC	VF	EO	EC	VF
Young	NS	NS	*	NS	*	NS
Middle-elder	NS	NS	*	NS	*	NS

EO: Eyes Open, EC: Eyes Closed, VF: Visual Feedback, %LOS: %Limits of Stability, %MA: %Max Area, NS: No Significant, *: significant difference, Wilcoxon signed rank sum tests

4. Discussion

PP and TS were measured by means of a static PBF examination in healthy young and middle-elder subjects, and standard values for young and middle-elder people were determined.

4.1. PBF in eyes open (EO), eyes closed (EC) and visual feedback (VF) conditions

PP among healthy subjects was 9.3% of the forward falling limit value and 0.01% to the right in the EO condition, 7.4% of the forward falling limit value and 0.01% to the right in the EC condition, and 0.03% of the backward falling limit value and 0.01% to the right in the VF condition. PP among healthy middle-elder subjects was 17.4% of the forward falling limit value and centered on the X axis in the EO condition, 21.8% of the forward falling limit value and 0.04% to the right in the EC condition, and 0.9% of the forward falling limit value and 0.02% to the right in the VF condition. Thus, it is harder to maintain a sense of balance in the EC condition than the EO condition.

When TS was compared between the EO and EC conditions, young people and middle-elder people swayed demonstrably more in the EC condition. Specifically, it has been previously demonstrated that the PBF is related to visual input, and closed eyes or impaired vision greatly affects TS [6]. Hageman et al. [19] reported a significant difference in TS between younger and older people in EO, EC and VF conditions. Subjects were also young people and middle-elder people in our study, and a significant contrast appeared between the young subjects and the middle-elder subjects in TS of EC and in PP of VF. It is considered that ability of middle-elder people to focus on fixation targets decreased due to their forward-inclined posture. It indicates that PBF is associated with visual input. The middle-elder subjects in this study had no diseases of the central nervous system, peripheral nervous system or musculoskeletal system, and the results are thought to concur.

The ratio of TS when upright standing with eyes open and eyes closed is called the Romberg ratio, and is used as an index of balance function that may reflect vestibular disorders. The values of 1.42 and 1.65 in our study were consistent with normal values between 1.2 and 2.2 [30].

4.2. Decrease in balance function due to aging

A gradual increasing trend in TS in standing posture was seen with increasing age, and the forward falling limit value was greater in middle-elder people than young people. That there was little TS in this study was believed to be because the subjects were healthy, and among the middle-elder subjects, there were few who had regressed in balance function. An increased amount of body sway was one of the changes characteristic of aging because the body sway area increased with aging [17]. Turano et al. [4] has published a report suggesting that the reasons that TS increases more in the EC condition than in the EO condition in elderly people are that the visual system contributes greatly to the physical balance adjusting function. When holding an upright standing posture physical balance adjusting functions other than the visual system regress markedly in elderly people. Static balance function has improved post-training compared with pre-training in strength training in electrical stimulation in elderly people [31], and before training in electrical stimulation in strength training. There have also been reports that no significant difference in body sway was seen between elderly and young people in standing posture in both EO and

EC conditions [20-22, 32], which did not agree with the hypothesis of decreased PBF due to aging.

The reason for differences among study reports on the ability of elderly people to maintain stability when sensory conditions change may have been that the subjects were diverse and may have had undetected pathologies. If neurological examinations were performed in subjects having no clear indication of lesions, it might clarify potential indicators of neuropathy that causes balance function impairment [33].

Imaoka et al. [34] compiled data of healthy people by conducting a TS survey in which basic data on Japanese people was compiled based on certain criteria in 2201 healthy men and women throughout Japan. There was a difference between men and women, and no major changes in mean center displacement of X-direction sway were seen at any age group. However, mean center displacement of Y-direction sway increased slightly with aging, and PP tended to move forward with age. These results agree with the data of our study.

4.3. Direction of TS and age

Compared to young people, middle-elder people exhibited a gradually increasing trend in sway to the left/right (X component) and forward/backward (Y component) directions, in both the EO and EC conditions. When the SD of the X component and Y component were compared, that of the X component was larger than that of the Y component in both the EO and EC conditions. It has been suggested that individual difference was greater in sway when standing in the left/right directions [32].

When TS was broken down into a forward/backward (Y) component and a left/right (X) component and the ratio (Y/X) was determined, the difference between left/right and forward/backward was greater in the middle-elder than in the young in both the EO and EC conditions with upright standing. The rate of increase of sway was greater in the EC condition; it has been suggested that the balance mechanism changes with aging, and in particular, balance adjusting functions other than the visual system regress markedly [17].

In the future, we will attempt to quantify TS characteristics in standing posture and changes in TS when visual information is provided as an objective index in orthoptics subjects with acquired ocular movement disorder. Physical balance is strongly related to visual input as the increasing rate of sway was greater in EC. It is suggested that the balance mechanism changes with aging, and in particular, balance adjusting functions other than the visual system regress markedly.

5. Conclusion

Physical balance function is closely related to visual input. When young and middle-elder subjects were compared, PP shifted in the forward direction and TS tended to increase with aging.

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