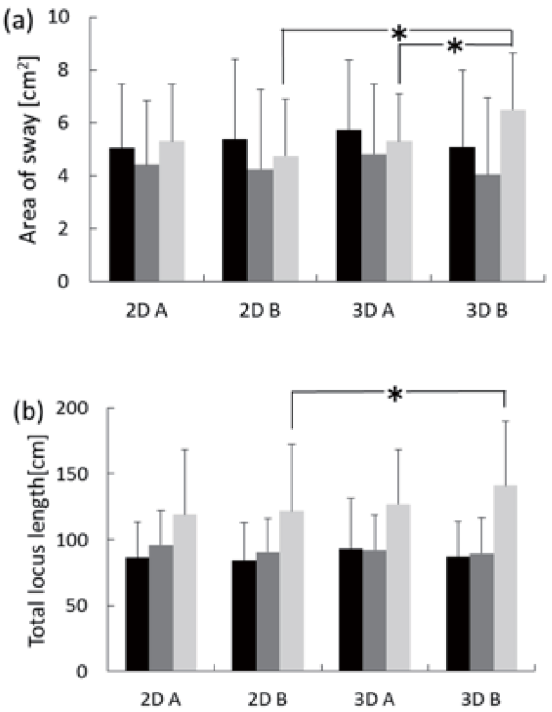

Fig. 2. Sway values in the elderly subjects with their eyes open; Area of sway (a), Total locus length (b). Black square: Young subjects; gray square: middle-aged subjects; white square: elderly subjects.

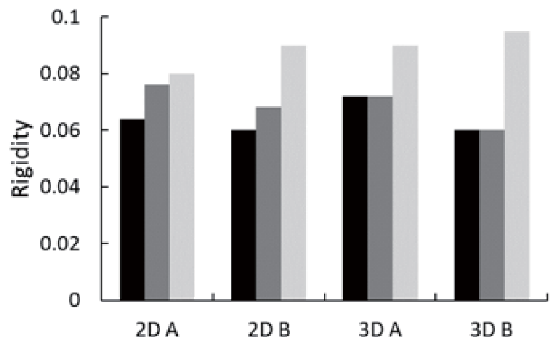

Fig. 3. Rigidity $\mu\Delta t$ under each condition (with their eyes open). Black square: Young subjects; gray square: middle-aged subjects; white square: elderly subjects.

3D with the perspective clues ($p < 0.05$). The total locus length per unit area while viewing the 3D without the perspective clues was significantly greater than that with eyes closed afterward ($p < 0.05$). No significant difference was noted in the other analytical parameters in the elderly subjects.

In the young subjects, the total locus length while viewing the 2D without the perspective clues was significantly greater than that in the test with closed eyes ($p < 0.05$). No significant difference was noted in the other analytical indices for stabilogram. In the middle-aged subjects, no significant difference was also noted in any indices.

Based on the Markov property and the x-y independence in components of the body sway, the Brownian motion is system proposed as a mathematical model to express the equilibrium function (Goldie *et al.*, 1986; Collins and De Luca, 1993). In general, stochastic processes including the Brownian motion are expressed by stochastic differential equations (SDEs) that are expected to apply to diagnose the vertigo. In contrast, we focused on the individuality of this equilibrium system and showed that it is necessary to consider the nonlinearity in the following SDE (Takada and Miyao, 2012);

$$\dot{z} = -gradU_z(z) + \mu w_z(t) \tag{1}$$

where μ and $w_z(t)$ express the noise coefficient and the white noise, respectively ($z = x, y$). This second term $\mu w_z(t)$ expresses small perturbation for the time-average potential function $U_z(z)$, which drives the COP. Assuming that the motion process is stationary without the anomalous diffusion, we have succeeded in deriving the relationship between the potential function $U_z(z)$ in each SDE and the stationary distribution $G_z(z)$ for each component of the body sway as

$$U_z(z) = -\frac{1}{2}\ln G_z(z) \tag{2}$$

under the condition of $\mu = 1$. However, this condition requests to normalize the data in the analysis of the time series. In this study, we employed numerical analysis of the SDE (1) including the coefficient μ, and we estimated the optimal value to reproduce form of the stabilogram. In this study, we assumed Histograms obtained from the stabilometry is regarded as stationary distributions (Takada, 2004). Based on Eq. (2), the potential functions are regressed to the parabolic polynomial as

$$\hat{U}_z(z) = az^2 + bz \tag{3}$$

by using the mean square method. Substituting this polynomial (3) into the first term in the right hand side of Eq. (1) as $U = \hat{U}$, we employed numerical analysis of the SDEs (1). Setting the initial value (x, y) to be $(0, 0)$, $w_z(t)$ is substituted to pseudo random numbers whose distribution is regarded to be uniform (mean $\pm$ standard deviation: 1 ± 1). Numerical solutions of 11,200 steps are herein obtained from the Runge-Kutta formulae of 4th degree of the Eq. (1) at $\mu = 1, 2, \ldots, 20$ and $\Delta t = 0.001, 0.002, \ldots, 0.01$ step, respectively. The first 10,000 steps of these are dumped due to the initial dependency, and the left 1,200 steps are acceptable as a numerical solution. Ten numerical solutions are calculated for each video clip. The total locus length Xs and the area of sway Ys are also estimated from the numerical solutions as well as the analysis of stabilograms measured in this study. Stabilograms resulted from the numerical solutions are evaluated by the residual sum of squares as

$$E = \left[\frac{\sqrt{Y_r}}{X_r}(X_r - X_s)^2 + (\sqrt{Y_r} - \sqrt{Y_s})^2\right]^{1/2}, \tag{4}$$

where square roots are calculated to adjust the dimension and scale difference between the total locus length and the area of sway. We herein assume that the stabilograms resulted from the numerical solutions are well reproduced at the coefficient condition $\mu\Delta t$ to minimize E in Eq. (4).