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Age-related Changes in Body Sway When Standing with Eyes Closed or Open and on Stable and Unstable Surfaces

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Abstract This study examined how the amount of body sway various by age when people are standing on either a stable or an unstable surface with eyes either open or closed. The participants were 83 healthy women ranging in age from their teens to their eighties (with 9 to 12 women in each of the eight 10-year cohorts). Body sway was measured for 60 s while the participants were standing on a force plate with foam rubber (stable posture) or without form rubber (unstable posture). Path length (in cm), envelopment area (in cm2), and the ratio between these two measures were selected as evaluation parameters. In a three-way analysis of visual, posture, and age factors, path length, and envelopment area showed a significant interaction. Path length was shorter with the rubber than without it for all age levels with the eyes open or closed. An age-level difference was found only when the eyes were open. The envelopment area was smaller with than without the rubber with the eyes open for all age levels except women in their thirties and for all age groups with the eyes closed. Again, a significant age-level difference was found only with the eyes open. The ratio of length to envelopment area demonstrated a significant main effect for factors of both posture and age level. It was greater without than with the foam rubber with the eyes open for all age levels except women from their twenties to their forties, and for all age levels with the eyes closed. Coefficients in the linear regression equations, calculated based on the means for each age level, were significant in for three parameters. Values of path length and envelopment area were smaller without than with the rubber, but no significant differences were found between these values with the eyes open and closed. In conclusion, body sway in all age levels is greater on a less stable surface and increases with age, but the effect of vision on body sway can be disregarded.

Keywords: *aging, foam rubber, static balance*

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1. Introduction

Standing posture is maintained by integrating in the cerebrum information from sensory sources (our vestibular, somatic, and visual systems) and transmitting it to the skeletal muscles throughout the body. The functions of these sensory organs decline with age [1,2]. Humans maintain a stable posture by slightly altering their center of gravity. Standing posture has been explained by using an inverted pendulum model [3,4,5]. The movement of the center of pressure (COP) has been used to evaluate body sway while people are maintaining a static posture [6,7,8,9] (Masani et al., 2007). Panzer et al. (1995) reported that COP sway during standing decreases with age. On the other hand, balance has also been evaluated in terms of COP sway on a less stable surface (Baloh et al., 1998). According to Fujimoto et al. [10], sway velocity and area, which are important indices of COP sway, increased during static standing on foam rubber (hereafter referred to as rubber). It is assumed that when one stands on the rubber, COP sway becomes larger due to unstable foot placement.

On the other hand, people normally maintain a collapsing posture by integrating vestibular, visuosensory, and somato-sensory information from the central nervous system (Demura et al., 2005). Among the three sensory systems, the visual system provides the most important input for humans’ postural stability, and a decline in visual functioning significantly affects postural control (Paulus et al., 1984). Masani et al. (2007) reported a difference between COP sway with the eyes open and closed among the elderly, but not among youth. However, because the support base changes when one is standing on an unstable surface, COP sway may differ between eyes-open and eyes-closed conditions in this situation even in young people.

Up to now, the rubber load test has been the primary means used to assess vestibular patients. It has been assumed that when one is standing on rubber, with eyes closed to remove visual input and disturb bathyesthesia so that maintaining stable posture is dependent mainly on the labyrinth system, COP sway will be more greatly affected than when one is standing on a flat floor with eyes open. This study examined age-related changes in body sway while women were standing on rubber (seen as causing postural instability) with their eyes either open or closed.

2. Methods

2.1. Participants

The participants were 83 healthy women from their teens to their eighties. Table 1 presents their descriptive characteristics. Before testing, the aims and procedures of this study were explained to the participants in detail, and written informed consent was obtained. The protocol for this study was approved by the Ethics Committee on Human Experimentation of the Faculty of Human Science, Kanazawa University.

2.2. Experimental Procedure

The participants were instructed to stand with their bare feet forming a 30° angle, their heels touching each other [10,11], and both arms hanging at their sides, and to look at a mark placed one meter in front of them. Because this posture is more stable than the Romberg posture [12], it was considered suitable for measuring body sway while on an unstable surface such as foam rubber. Measurement began after each participant's hand position, sight line, and postural stability were all confirmed. Body sway when standing on a force plate both with and without rubber and with the eyes open or closed was measured in random order, for a time period of 1 min for each of the four possible combinations. The observations took place in a quiet room with sufficient light and 60 s of resting time between measurements. Those participants who normally wore glasses or contact lenses continued to do so while performing the tests.

2.3. Experimental Equipment

The Gravi coder G620 (Anima Co., Ltd., Japan) was used in this study. This equipment can calculate COP of vertical loads from the values of three vertical load sensors, which are located in the corners of an isosceles triangle on a level surface. The data sampling frequency was set at 50 Hz. The foam rubber (ANIMA, Japan; thickness 3.5 cm, tension strength 2.1 kg/cm^2, density 0.06 g/cm2, stretch rate 110%) used in this test deforms depending on weight distribution because its material resembles a soft cushion. The rubber can be placed on the G620 without any type of attachment (see Figure 1).

Figure 1. Gravi coder G620 (left) and foam rubber (right)

2.4. Parameters

In this study, the path length (LNG, measured in cm), envelopment area (EA, measured in cm^2), and ratio of length to envelopment area were selected as parameters to evaluate the length, area, and velocity of body sway, respectively. Demura et al. [9] and Kitabayashi et al. [13] reported that these were effective parameters for the evaluation of body sway because of their logical validity and inter-trial reliability. LNG represents the total distance that the COP moves, so a larger value means greater body sway. EA is the area surrounded by the outermost border of the COP; again, a larger value signifies greater body sway. LNG/EA (the path length divided by the envelopment area) is calculated because a larger value represents faster body sway.

2.5. Statistical Analysis

A three-way analysis of variance without correspondence (visual, posture, and age level) was used to examine the mean differences in body sway. A multiple test was performed when a significant interaction or main effect was found. In the regression equation, each sway parameter was the dependent variable (y), and the subject's age was the independent variable (x). The significance of regression coefficients was examined by using the *t*-test. Statistical analyzes were performed using SPSS for Windows 11.4J. The level of statistical significance was set at 5%. Statistical significance was adjusted based on Bonferroni's method for purposes of comparison among the means for each condition.

Table 1. Characteristics (age, height, and weight) of the participants

		Teens	20s	30s	40s	50s	60s	70s	80s
N		10	11	10	12	11	9	10	9
Age (years)	Mean	15.3	22.7	33.8	45.2	53.9	65.4	75.0	83.6
	SD	0.5	1.5	3.3	3.0	2.3	2.6	1.7	2.4
Height (cm)	Mean	158.5	160.8	158.8	160.3	155.5	153.9	147.2	146.1
	SD	2.4	2.5	4.3	5.0	5.9	6.7	5.3	6.3
Weight (kg)	Mean	50.4	54.2	51.0	56.1	52.4	56.3	49.8	48.6
	SD	5.8	7.5	3.5	3.4	5.7	9.5	7.6	4.4

Table 2. Means and standard deviations according to vision, posture, and age level, and results of ANOVA for sway parameters

Parameter	Vision	Posture		10's (n = 10)	20's (n = 11)	30's (n = 10)	40's (n = 12)	50's (n = 11)	60's (n = 9)	70's (n = 10)	80's (n = 10)	Three-way ANOVA	F-value	p	Multiple comparison
path length (LNG:cm)	Eyes open	off foam rubber	Mean	86.4	93.4	89.6	118.5	118.8	122.9	148.8	158.4	F1	134.95*	0.00	Eyes open
			(SD)	(15.0)	(20.0)	(16.5)	(20.8)	(35.0)	(24.9)	(44.6)	(34.9)	F2	326.05*	0.00	on foam rubber: 10's < 40's–80's, 20's–30's < 70's
		on foam rubber	Mean	54.1	59.3	59.7	71.0	63.7	73.7	81.0	87.7	F3	10.39*	0.00	20's–60's < 80's
			(SD)	(10.8)	(15.2)	(14.6)	(21.8)	(18.0)	(21.0)	(24.7)	(21.2)	F4	47.76*	0.00	off-foam rubber: 10's < 80's
	Eyes closed	off foam rubber	Mean	175.1	160.4	176.1	183.4	196.3	216.1	252.3	216.5	F5	0.73	0.64	All ages: on foam rubber > off foam rubber
			(SD)	(46.1)	(37.8)	(56.7)	(42.6)	(59.0)	(45.7)	(119.4)	(47.9)	F6	1.59	0.14	
		on foam rubber	Mean	74.1	75.5	75.2	91.1	77.4	105.5	111.3	103.3	F7	0.27	0.97	Eyes closed
			(SD)	(22.4)	(30.0)	(22.7)	(36.5)	(27.1)	(39.6)	(54.6)	(24.4)				All ages: on foam rubber > off foam rubber
envelopment area (EA: cm2)	Eyes open	off foam rubber	Mean	3.5	5.2	4.5	6.0	7.0	6.4	9.8	11.6	F1	63.01*	0.00	Eyes open
			(SD)	(1.9)	(3.4)	(3.3)	(4.1)	(2.4)	(3.0)	(3.4)	(4.2)	F2	250.5*	0.00	on foam rubber: 10's–30's < 70's, 10's–60's < 80's
		on foam rubber	Mean	1.9	3.4	3.3	4.1	2.4	4.4	3.4	4.2	F3	7.94*	0.00	off foam rubber:–
			(SD)	(1.1)	(1.5)	(2.3)	(3.2)	(1.0)	(3.0)	(2.1)	(1.7)	F4	42.85*	0.00	10's, 30's–80's: on foam rubber > off foam rubber
	Eyes closed	off foam rubber	Mean	8.6	10.6	9.8	10.4	13.0	14.3	15.9	15.0	F5	0.65	0.72	
			(SD)	(3.5)	(4.2)	(5.0)	(4.5)	(6.6)	(4.3)	(7.5)	(5.8)	F6	4.45	0.00	Eyes closed
		on foam rubber	Mean	2.6	3.6	3.3	4.4	3.0	3.0	4.2	4.4	F7	0.26	0.97	All ages: on foam rubber > off foam rubber
			(SD)	(1.8)	(1.8)	(2.0)	(4.0)	(1.9)	(1.9)	(3.2)	(2.0)				
length/envelopment area (LNG/EA: cm/cm2)	Eyes open	off foam rubber	Mean	28.0	19.3	22.1	23.4	20.5	20.8	16.6	14.5	F1	0.03	0.86	Eyes open
			(SD)	(11.1)	(5.5)	(6.0)	(9.8)	(9.8)	(6.4)	(4.3)	(5.5)	F2	57.97*	0.00	on foam rubber:–
		on foam rubber	Mean	40.7	19.4	22.9	28.5	30.4	30.3	30.0	22.8	F3	4.29*	0.00	off foam rubber:10's > 20's, 30's, and 80's
			(SD)	(24.4)	(6.1)	(9.2)	(19.3)	(14.2)	(13.5)	(14.4)	(5.7)	F4	3.20	0.07	10's and 50's–80's: off foam rubber > on foam rubber
	Eyes closed	off foam rubber	Mean	21.7	16.3	19.4	20.4	17.8	17.2	17.1	16.5	F5	0.47	0.85	
			(SD)	(5.5)	(4.1)	(5.0)	(9.4)	(9.0)	(8.6)	(7.0)	(7.1)	F6	1.40	0.20	Eyes closed
		on foam rubber	Mean	36.7	24.1	27.4	31.3	35.4	31.2	31.9	25.5	F7	0.15	0.99	All ages: on foam rubber > off foam rubber
			(SD)	(5.5)	(4.6)	(5.0)	(9.4)	(9.0)	(14.6)	(7.0)	(7.1)				

Note: * $p < 0.05$; F1: vision, F2: posture, F3: age level, F4: vision x age level, F5: vision x posture, F6: posture x age level, F7: vision x posture x age level.

3. Results

Table 2 shows the means and standard deviations according to vision, posture, and age level as well as the ANOVA results for the sway parameters. LNG and EA showed a significant interaction.

The multiple comparison tests showed that LNG was shorter with than without the rubber for all age levels, with the eyes either open or closed. A difference by age level was found only when the eyes were open; this difference was significantly smaller among participants in their teens than among those in their eighties. Without the rubber, significant differences appeared between participants in their teens and those in their forties to eighties; with the rubber, there were significant differences between participants in their twenties to thirties and those in their seventies, and between those in their twenties to sixties and those in their eighties. Regardless of the presence or absence of the rubber, LNG was shorter when participants had their eyes open. The effect size (d) of the mean difference between participants in their teens and those in their eighties was large (0.88–2.74), regardless of the presence or absence of the rubber or whether the eyes were open.

In contrast, EA was smaller with than without the rubber for all age levels with the eyes open except those in their thirties, and for all age groups with the eyes closed. An age-level difference was found only with the eyes open. EA was significantly larger for participants in their eighties than for those in their teens to sixties, and for participants in their seventies than for those in their teens to thirties without the rubber. The effect size (d) of the mean difference between the participants in their teens and those in their eighties was large (0.97–3.71), regardless of whether the rubber was present of the rubber or the visual condition.

LNG/EA indicated a significant main effect for both posture and age level. In the multiple comparison test, it was greater without than with the rubber for all age levels except those in their twenties to forties with the eyes open, and for all age levels with the eyes closed. In addition, it was greater for participants in their teens than for those in their twenties, thirties, or eighties without the rubber with the eyes open; however, there was no significant difference between any age levels with the rubber absent and the eyes closed. The effect size (d) of the mean difference between the participants in their teens and those in their eighties was large (0.82-1.52), regardless of the presence or absence of the rubber or of the visual condition.

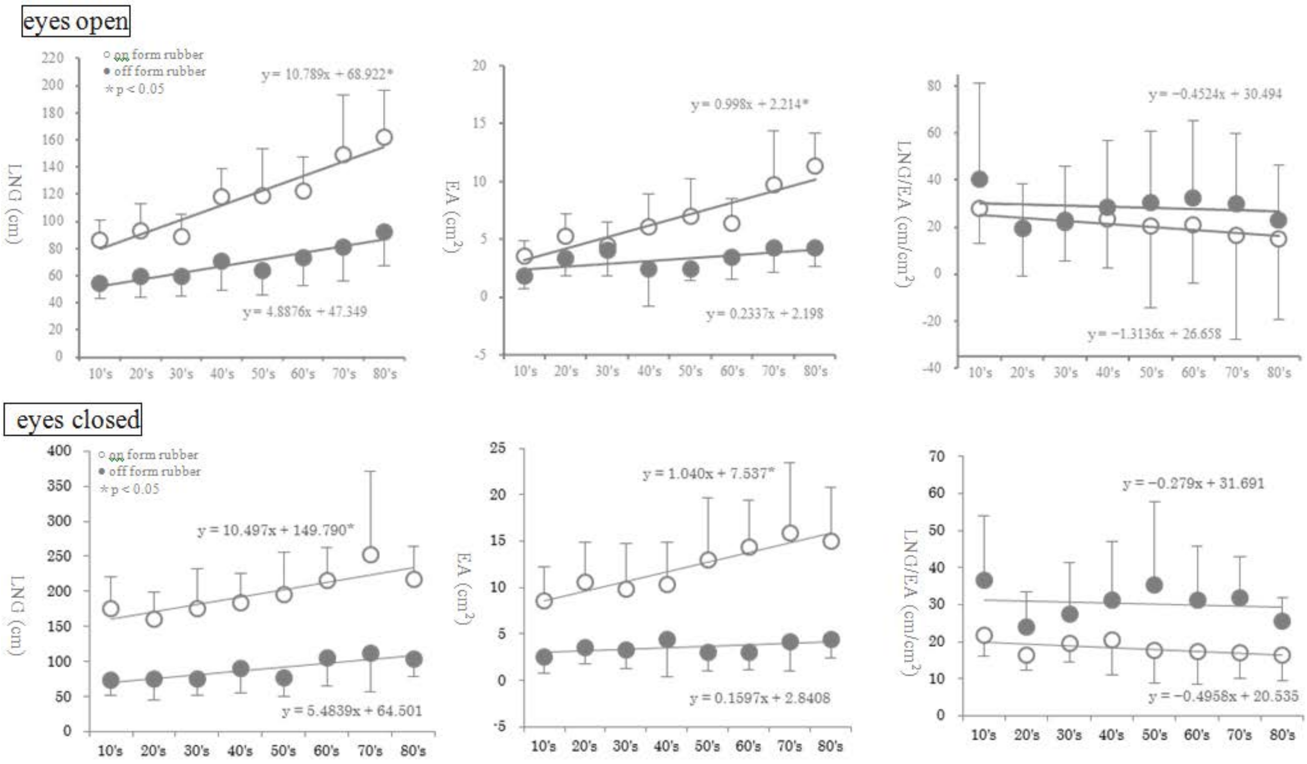

Figure 2. Regression equations with and without the foam rubber for the COP parameters (path length, envelopment area, and path length/envelopment area)

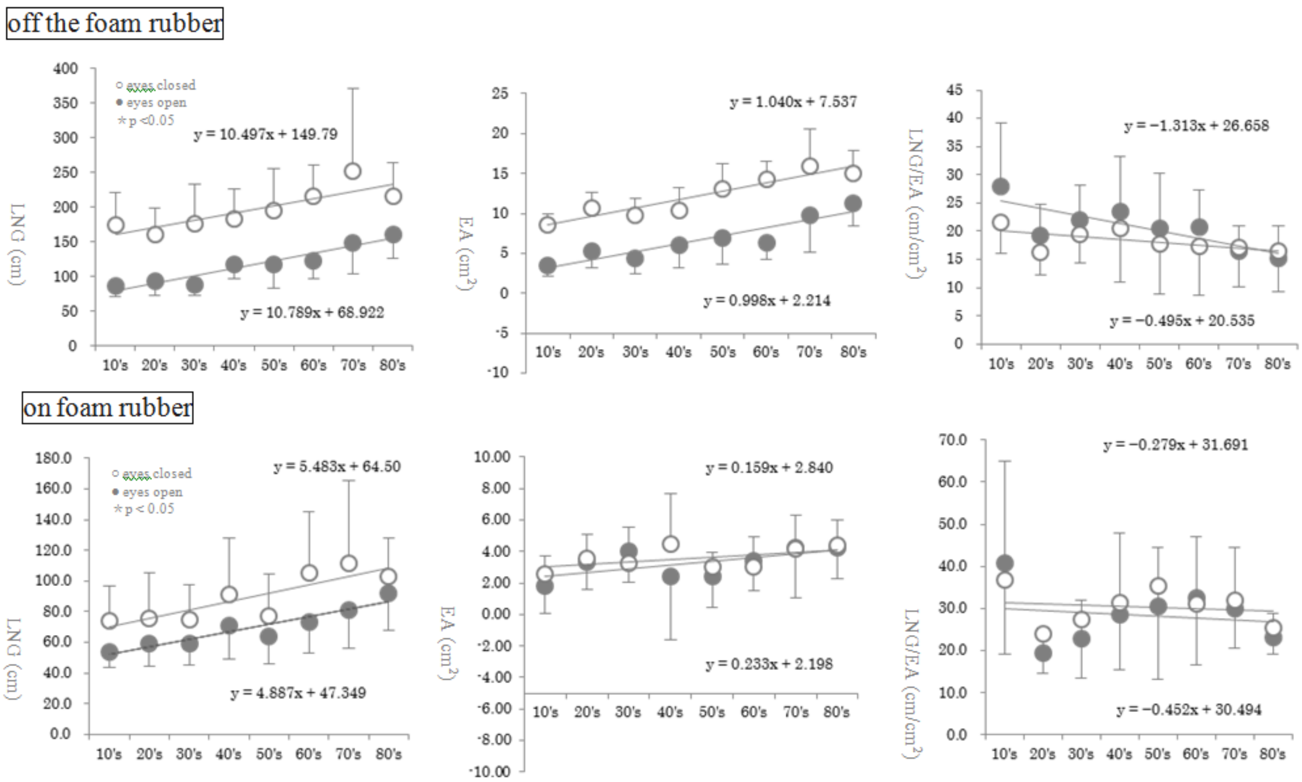

Figure 3. Regression equations with eyes open and closed for the COP parameters (path length, envelopment area, and length/envelopment area)

Figure 2 shows the regression equations with and without the rubber for the COP parameters. All regression coefficients were significant. Significance was found in the regression coefficients with the eyes open (10.7 and 4.8, respectively) and closed (10.4 and 5.4) for LNG as well as in the regression coefficients with the eyes open (0.9 and 0.2) and closed (10.4 and 0.1) for EA. All parameters were larger with than without the rubber.

Figure 3 shows the regression equations with the eyes open or closed for the COP parameters. All regression coefficients were significant, but significant differences were not found in all coefficients.

4. Discussion

Allum and Pfaltz (1985) reported that visual information is the primary contributor to maintaining stable posture while standing. When visual information is intercepted, information from the vestibular and somato-sensory systems can compensate for this loss and enable people to maintain a stable posture, but body sway increases, demonstrating the greater difficulty involved in keeping one’s stability. The elderly are especially dependent on visual information for posture control (Mizukoshi, 1993), and their postural sway during walking differs depending on whether their eyes are open or closed (Brenton et al., 2011). Aoki et al. (2012) reported that the contribution of visual information to posture control increases with age. In the present study, LNG and EA were larger with the eyes closed than open, and this difference tended to increase with age. The declining performance of the vestibular and somato-sensory functions that compensate for a decrease in visual functioning may be responsible for this result [14]. In addition, the regression coefficients of LNG and EA with the eyes open or closed were significant regardless of whether rubber was present. Hence, it can be inferred that both the size and length of the body sway increase with age.

LNG and EA were larger with than without the presence of foam rubber. These results are consistent with those of Fujimoto et al. [10]. It is believed that the amount of body sway increased because the somatic input from the feet was limited by the rubber. Moreover, both parameters increased with age, and the degree of increase was greater with than without the rubber. When standing on stable surfaces, humans maintain their standing posture by adjusting the tension of different muscle groups related to the ankle joints. Standing on foam rubber requires more muscle tension because it increases the moment arm needed to recover posture. Vendervoot and McComas [15] reported that ankle moment begins to decline when people reach their sixties. Lin Woollacott [16] indicated that balance ability when stabilizing one’s posture is related to leg strength. Among elderly people, Larson et al. (1979) found that muscle strength decreased by 1.5% in one year, and Frontera et al. (2000) found a decrease of 1.4% to 2.5% in one year. Presumably, this decrease of leg strength and ankle joint ability with age makes maintaining posture control on foam rubber more difficult, and for this reason body sway increased among older people.

The super-elderly (in their seventies and eighties) showed the largest body sway. It was larger with the eyes closed, but the coefficient between the two visual conditions (open and closed) was not statistically significant. Hence, it is believed that the increase in body sway with age while on the foam rubber was largely affected by a decrease in the vestibular and somato-sensory functions rather than in the visual function. In contrast, LNG/EA, which evaluated the velocity of body sway, showed a significant age-level difference without the rubber but not with the rubber. Kouzaki and Masani [17] reported that LNG/EA values for the elderly were higher than those for young adults. In the present results, a significant age difference was found in LNG/EA when the rubber was not present (i.e., in a stable posture). However, the results of the regression analysis showed no significant coefficient differentiating these two conditions (i.e., with and without the rubber). Therefore, it is believed that the effect of the rubber on this parameter may be small and that body sway velocity is not greatly affected by a decrease in vestibular and somato-sensory functions.

5. Conclusion

In conclusion, body sway in all age levels increases when one is standing on foam rubber. The extent of body sway increases with age, but the effect of vision can be disregarded.

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