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Evaluating the effects of open/closed eyes and age-related differences on center of foot pressure sway during stepping at a set tempo

Hiroki Aoki[1*], Shinichi Demura[2], Haruka Kawabata[2], Hiroki Sugiura[2], Yu Uchida[2], Ning Xu[3], Hitoshi Murase[4]

[1]Kanazawa College of Art, Kanazawa, Japan; [*]Corresponding Author: aoki@kanazawa-bidai.ac.jp
[2]Graduate School of Natural Science & Technology, Kanazawa University, Kanazawa, Japan
[3]Graduate School of Human and Socio-Environmental Studies, Kanazawa University, Kanazawa, Japan
[4]Anima Corporation, Tokyo, Japan

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ABSTRACT

This study aimed to examine the effects of open/closed eyes and age difference on Center of Foot Pressure (COP) sway during stepping. The subjects were 87 healthy males aged 10 - 80 years. COP was measured 20 times when subjects stepped on two force plates (left and right) at a rate of 60 steps/min. The evaluation parameters selected were: total trace length, velocity, circumference, rectangular area, left-right width, and front-back width. The former four of these parameters were found to be significantly lower with eyes open than eyes closed in 80-year-old subjects, while the last parameter was significantly lower with eyes open in 10-year-old subjects. In 70- and 80-year-old subjects with eyes open, circumference was greater than that in 10- and 40 - 60-year-old subjects; their rectangular area was greater than that in 50- and 60-year-old subjects; and their front-back width was greater than that in 10- and 30 - 60-year-old subjects. With eyes closed, circumference, rectangular area, left-right width, and front-back width in 80-year-old subjects, were greater than those in 10 - 70-year-old subjects. The front-back width during stepping with eyes closed was greater in 70- and 80-year-old subjects than in 30 - 50-year-old subjects. The Romberg quotient for all COP sway parameters revealed no significant age-related differences. From our findings, a difference in body sway was observed in 80-year-old subjects (with eyes open/closed) when compared with the other age groups. In addition, the extent of sway varied little among <60-year-old subjects. However, COP sway was greater with eyes open in 70- and 80-year-old subjects compared with <60-year-old subjects, and greater with eyes closed in 80-year-old subjects compared with <70-year-old subjects. In conclusion, >80 year-old-subjects have greater body sway during stepping, particularly with eyes closed.

Keywords: Elderly; Dynamic Balance; Tempo; Stepping; Center of Foot Pressure (COP)

1. INTRODUCTION

Posture control during standing is closely related to basic human movements such as walking and standing up. To date, the Center of Foot Pressure (COP) has been used to evaluate postural control ability of humans [1,2]. COP sway during standing has a close relationship with static balance [3-5], and sway characteristics have been studied in various age groups from infants to the elderly [5,6]. Using COP sway during stepping, Ohnishi *et al.* [7] evaluated dynamic balance of the movements that change the support base such as walking and ascending and descending stairs. They examined the age-related differences in total trace length of COP sway at 80%, 70%, and 60% of Maximum Step Length (MSL) of the Rapid Step Test (RST) and reported that RST was greater in the elderly than in the young under all MSL conditions. Fujiwara *et al.* [6] examined age-related differences of COP during forward and backward bending postures in subjects aged 20 - 70 years, and reported that the trace length lengthened with age and that the front-back width of the effective support base (which is an index of balance) differed between 60-year-old and 70-year-old subjects. In recent times, most developed nations comprise a greater proportion of individuals >80 years in their population. Although these individuals are able to live independently, they tend to become unstable even while standing up and walking, which are basic daily movements. This occurs due to a marked reduction in various physical functions including balance and leg strength; hence, falling over is more likely. Therefore, it is important to prevent or discourage the decrease of physical functions that are closely related to daily life movements and to evaluate them accurately. Shin & Demura [8] recently evaluated dynamic balance in the elderly using stepping movements. Because stepping on the spot alters the supporting base in a similar way as in RST, COP during stepping may be different between the young and the elderly.

On the other hand, people normally prevent a collapsing posture by integrating vestibular, visuosensory, and somatosensory information from the central nervous system [1]. Of these three senses, the visual system has a very important role in maintaining stable posture, and it has been postulated that reduced visual function markedly affects postural control [9]. In regard to postural control, the elderly were found to have greater dependence on visual information than the young [10]. Masani *et al.* [11] reported a difference in COP sway in the elderly between open/closed eyes, but not in the young; in addition, Brenton *et al.* [12] reported this difference in the elderly. As mentioned above, it is hypothesized that the contribution of visual information to postural control increases with age; in short, an age-related difference in COP exists between the conditions of open/closed eyes. In stepping movements at a set tempo, subjects use only one leg support to control their physical center of gravity while adhering to a set tempo; hence, this may be a more difficult exercise than RST. Consequently, the following is assumed: a difference between open/closed eyes in relation to COP sway during stepping at a set tempo is more marked in the elderly than in the young. In addition, especially the very elderly, find it difficult to maintain stable posture when the weight is supported by one leg due to reduction in strength of the leg musculature; sub sequently, they may show a greater COP change in the left-right direction when compared to the young, particularly with eyes closed.

This study aimed to examine the effect of open/closed eyes and age on COP sway during stepping at a set tempo.

2. METHODS

2.1. Subjects

The subjects were 87 healthy males aged 10 - 90 years. Sample sizes of each 10-year age group ranged from 10 to 13. **Table 1** shows means of the age, height, and weight of each group. We explained the purpose, methods, and risks of the study protocol to the subjects and obtained their consent. The study protocol was approved by the Kanazawa University Department of Education.

2.2. Experiment Equipment and Methods

Equipment

A stabilometer (GP-31W; Anima, Tokyo, Japan) was used to measure COP during stepping. This machine calculates COP of vertical loads from the values of three vertical load sensors located at the corners of an isosceles triangle on a leveled surface. The data sampling frequency was 20 Hz.

Study methods

The subjects stood on two platforms (left and right) with arms rested comfortably on their sides. They were instructed to focus on the central fixation target with eyes open and then to gradually close them. After this, they were instructed to step 40 times in synchrony with a beeping sound (60 steps/min). All the trials were conducted once with eyes open and once with eyes closed.

2.3. Parameters

The following evaluation parameters of the center of gravity were selected:

Total trace length (the full length that COP moved during stepping); velocity (mean velocity); circumference

Table 1. Basic statistics of subjects'age, height, and weight.

	Age (year)		Height (cm)		Weight (kg)	
	Mean	SD	Mean	SD	Mean	SD
10-year-old	16.3	1.6	170.4	5.3	56.7	6.6
20-year-old	22.3	2.0	173.6	4.5	69.0	8.0
30-year-old	34.6	2.2	173.2	4.2	78.6	5.6
40-year-old	45.8	2.0	171.8	2.9	77.9	13.5
50-year-old	54.8	2.6	170.3	4.3	70.8	9.2
60-year-old	64.9	3.3	164.0	4.7	64.7	9.0
70-year-old	74.4	3.0	159.5	7.6	57.9	12.0
80-year-old	83.4	3.4	160.3	7.1	58.6	9.3

(medial area surrounded by circumference of a trace of COP sway); rectangular area (bounded by front-back circumference and horizontal direction of sway); left-right width (greatest deflection distance); and front-back width (greatest deflection distance). When these have a large variation, postural control ability is evaluated to be inferior.

2.4. Data Analysis

One-way non-repeated analysis of variance (ANOVA) measures were used to clarify age-related differences by Romberg quotient. Two-way ANOVA (one-factor repeated-measures) was used to clarify the mean differences in age and eyes open/closed values for COP sway parameters. When a significant interaction or effect was found, Tukey's Honestly Significant Difference (HSD) test was used for multiple comparisons. The level of significance was determined as 0.05.

3. RESULTS

Table 2 displays the test results for age-related differences by Romberg quotients for COP sway parameters. No significant age-related differences were found in all the parameters.

Table 3 shows the results of two-way ANOVA (age and eyes open/closed) for COP parameters. Total trace length, velocity, circumference, rectangular area, and left-right width were significantly less with eyes open than eyes closed in 80-year-old subjects, and front-back width was significantly less with eyes open than eyes closed in 10-year-old subjects. In 70- and 80-year-old subjects with eyes open, the circumference was greater than that in 10- and 40 - 60-year-old subjects; rectangular area was greater than that in 50- and 60-year-old subjects; and, front and back width was greater than that in 10- and 30 - 60-year-old subjects. With eyes closed, circumference, rectangular area, left-right width, and front-back width were greater in 80-year-old subjects than those in 10 - 70-year-old subjects. The front-back width during stepping with eyes closed was greater in 70- and 80-year-old subjects than in 30 - 50-year-old subjects.

4. DISCUSSION

There were insignificant differences in 10 - 60-year-old subjects in COP sway parameters: circumference, rectangular area, left-right width, and front-back width in both the cases (eyes open/closed). Duncan *et al.* [13] reported that the performance of a Functional Reach Test (FRT) was 94.6% in 41 - 69-year-old subjects and to 72.0% in 70 - 87-year-old subjects when using the results of 20 - 40-year-old subjects as the criteria for comparison. The above results suggest that FRT was maintained at about 95% of that of the young until about 70 years of age, indicating a minimal decrease in performance with age. Himann *et al.* [14] reported that walking speed decreases 12% - 16% every 10 years after 60 years of age. In old age, dynamic balance contributes considerably to walking due to decreased leg muscle function. Because a step test with stipulated tempo demands subjects to step while matching tempo and to stand with one leg, dynamic balance relates strongly to achieve the test [8]. Although the test used in the present study requires a different type of balance from that in FRT or walking test, >70-year-old subjects may find it very difficult to per- form the step movement due to markedly decreased dynamic balance.

In <70-year-old subjects, total trace length, velocity, circumference, rectangular area, and left-right width revealed insignificant differences with eyes open/closed.

Table 2. Basic statistics and results of one-way ANOVA of Romberg quotients for COP sway parameters.

	10-year-old		20-year-old		30-year-old		40-year-old		50-year-old		60-year-old		70-year-old		80-year-old	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total trace length	1.04	0.04	1.02	0.04	1.01	0.05	1.04	0.05	1.05	0.06	1.04	0.08	1.03	0.06	1.08	0.08
Velocity	1.03	0.04	1.02	0.04	1.00	0.05	1.05	0.06	1.06	0.05	1.04	0.08	1.05	0.07	1.09	0.09
Circumference	1.32	0.14	1.15	0.18	1.20	0.26	1.24	0.29	1.36	0.22	1.30	0.25	1.25	0.37	1.52	0.40
Rectangular area	1.39	0.19	1.13	0.16	1.16	0.19	1.24	0.27	1.31	0.25	1.31	0.30	1.20	0.30	1.40	0.36
Left-right width	1.10	0.10	1.07	0.08	1.06	0.05	1.09	0.08	1.11	0.07	1.06	0.07	1.09	0.12	1.13	0.15
Front-back width	1.26	0.12	1.05	0.11	1.09	0.15	1.14	0.21	1.18	0.19	1.22	0.23	1.10	0.28	1.23	0.27

df: degree of freedom

Table 3. Basic statistics and results of two-way ANOVA for COP parameters.

	Total trace length (cm)		Velocity (cm/sec)		Circumference (cm^2)		Rectangular area (cm^2)		Left-right width (cm)		Front-back width (cm)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Eyes open												
10 yr	1027.3	107.6	41.8	4.3	132.0	23.9	238.5	38.7	20.8	1.6	11.5	2.0
20 yr	1097.7	144.3	44.6	5.9	167.8	35.7	293.0	65.0	21.4	2.0	13.6	2.2
30 yr	1035.0	126.6	42.4	5.2	148.5	37.0	269.2	57.4	21.4	2.2	12.5	1.7
40 yr	1017.1	125.4	41.6	5.5	138.9	26.8	241.3	39.4	21.1	2.0	11.4	1.3
50 yr	937.2	140.0	38.0	5.7	120.6	29.0	215.9	51.5	19.5	2.2	11.0	1.6
60 yr	962.6	101.9	39.3	4.1	131.6	27.5	233.6	50.8	20.2	1.9	11.6	2.2
70 yr	946.9	153.2	38.2	6.9	189.1	93.5	320.3	142.9	20.5	2.3	15.6	5.9
80 yr	1035.6	164.0	42.1	7.1	225.8	106.8	405.1	199.7	23.0	3.4	17.1	7.1
Eyes closed												
10 yr	1067.4	132.0	43.2	5.2	174.3	37.1	331.8	79.2	22.9	2.0	14.4	2.5
20 yr	1118.4	147.8	45.5	6.0	191.4	40.3	328.5	70.7	22.8	1.9	14.3	2.4
30 yr	1039.3	106.2	42.4	4.3	171.1	24.9	304.2	36.7	22.6	1.5	13.5	1.2
40 yr	1053.9	104.5	43.6	5.0	169.9	38.6	296.7	74.1	22.9	2.2	12.9	2.3
50 yr	973.9	116.5	40.0	4.8	160.2	33.0	275.8	56.7	21.5	1.6	12.8	2.1
60 yr	994.8	102.2	40.8	3.9	172.5	57.5	301.9	88.8	21.5	2.3	13.9	2.9
70 yr	972.0	177.1	40.1	8.1	214.0	72.7	363.9	142.5	22.5	4.8	15.9	3.7
80 yr	1119.1	195.0	45.8	8.1	320.7	122.4	528.6	220.7	26.0	4.8	19.7	5.7

	F1	F2	F3
Total trace length	1.95 (df:7,df:79)	27.94* (df:1,df:79)	1.41 (df:7,df:79)
Velocity	1.75 (df:7,df:79)	36.93* (df:1,df:79)	1.77 (df:7,df:79)
Circumference	6.85* (df:7,df:79)	72.45* (df:1,df:79)	3.00* (df:7,df:79)
Rectangular area	5.47* (df:7,df:79)	71.14* (df:1,df:79)	2.03 (df:7,df:79)
Left-right width	2.67* (df:7,df:79)	62.70* (df:1,df:79)	0.77 (df:7,df:79)
Front-back width	5.28* (df:7,df:79)	35.05* (df:1,df:79)	1.45 (df:7,df:79)

Post-hoc

Total trace length	80 yr: O < C		
Velocity	80 yr: O < C		
Circumference	80 yr: O < C	O 10 yr·40 - 60 yr < 70 yr·80 yr, 20 yr·30 yr < 80 yr	C 10 - 40 yr·60 yr·70 yr < 80 yr, 50 yr < 70 yr·80 yr
Rectangular area	80 yr: O < C	O 10 yr·50 yr·60 yr < 70 yr·80 yr, 20 - 40yr·70 yr < 80 yr	C 10 - 40 yr·60 yr·70 yr < 80 yr, 50 yr < 70 yr·80 yr
Left-right width	80 yr: O < C	O 50 yr·60 yr < 80 yr	C 10 yr - 70yr < 80 yr
Front-back width	10 yr: O < C	O 10 yr·30 - 60 yr < 70 yr·80 yr, 20 yr < 80 yr	C 10 yr·20 yr·60 yr·70 yr < 80 yr, 30 - 50 yr < 70 yr·80 yr

yr: year-old, O:eyes open, C: eyes closed, df: degree of freedom.

When examining the effect of eyes closed on COP parameters, the Romberg quotient (eyes closed sway/eyes open sway) is generally used [15]. Romberg quotients in our study for total trace length at all age levels were in the range 1.00 - 1.04; in short, they continued to be low regardless of age levels. Shin & Demura [16] reported that similar to the other age levels, the elderly could achieve cyclic exercises performed daily such as walking with stable posture. Because stepping at a tempo of 60 steps/min resembles walking and is a periodic exercise performed on the spot [16], it is considered that even the elderly could step with a stable posture regardless of eyes open/closed. Consequently, this explains our observation of minimal difference in COP sway in relation to eyes open/closed.

Romberg quotients were not different among age groups for all the parameters; however, we could confirm that COP sway parameters differed for 80-year-old subjects in regard to eyes open/closed. Lin & Woollacott [17] reported that balancing ability relates to leg strength. Frontera *et al.* [18] studied longitudinal changes in muscle strength of the elderly (65.4 ± 4.2 years) and reported that this decreased by 1.4% - 2.5% over one year. Moreover, Larson *et al.* [19] reported that muscle strength decreased by 1.5% every year after 60 years of age. The marked decrease in leg strength of >80-year-old subjects creates difficulties in stepping while maintaining posture. However, when the eyes are closed stepping is dependent on somatosensory and vestibular information only. Thus, in the very elderly, COP sway during stepping may vary depending on whether the eyes are open or closed. Furthermore, predominantly in very elderly individuals, marked reduction in various physical functions including dynamic balance can lead to an increase in fall anxiety caused by sight restriction. However, in our study, they compensated for this by taking larger steps when the eyes were closed rather than eyes opened, thereby increasing COP sway.

With eyes open, 80-year-old subjects recorded greater circumference and left-right width than <60-year-old subjects; however, with eyes closed, circumference, rectangular area, left-right width, and front and back width were greater than those in <70-year-old subjects. In short, age-related differences in COP sway during stepping differed between eyes open and eyes closed. It was confirmed that the hip abductor muscle groups contribute to the stability of lateral movements of the pelvis during stepping [20]. Furthermore, a decrease in muscle strength (e.g., anterior tibial and peroneal muscles) related to plantar flexion and dorsiflexion exercise of the ankle relates to stability of the trunk and head [21]. In short, leg strength is closely related to dynamic balance, which maintains stability during standing. The stepping procedure at a set tempo used in this study requires the subject to support the body with either leg alternately; however, when leg strength decreases it becomes difficult to step while maintaining postural stability. This becomes more difficult with eyes closed which interrupt the sight. The foregoing indicates the possibility that COP sway during stepping with eyes closed is greater in 80-year-old subjects when compared with younger subjects.

In addition, the COP sway (front-back width) during stepping with eyes closed was greater in 70- and 80-year-old subjects than in 30-50-year-old subjects. According to Ikai *et al.* [22], reaction to disturbance stimulation is slower in elderly (65 - 75-year-old) than in middle-aged individuals (45 - 55-year-old). In-place stepping is a kind of disturbance stimulation. The super elderly have marke dly decreased leg strength; therefore, it is inferred that the degree of dependence on sight information for postural control becomes relatively high. This limitation largely affects the maintenance of a stable posture. Therefore, there is a possibility that COP sway is different between the elderly individuals aged above 70 years (super elderly) and middle-aged individuals.

As stated above, super elderly individuals with decreased leg strength find it difficult to support the body with a single leg and step while maintaining postural stability; this can affect COP sway during stepping. To decrease the degree of physical sway, it is essential to ensure accurate sight information and increased leg strength in the super elderly.

5. CONCLUSION

We observed a significant difference in body sway of >80-year-old subjects during stepping between eyes open and eyes closed, unlike other subjects. In addition, regardless of whether the eyes were open or closed, we observed minimal difference in COP sway during stepping in <60-year-old subjects. Furthermore, COP with eyes open, was greater in the 70- and 80-year-old subjects than the same in <60-year-old subjects; COP with eyes closed was greater in 80-year-old subjects when compared with <70-year-old subjects.

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