

Comparison by Gender and Age and Their Mutual Relations with Center of Pressure Variables

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Received October 20, 2025; Revised November 24, 2025; Accepted December 01, 2025

Abstract Individuals have unique sway characteristics, and to clarify interindividual variations, we must determine time points at which age and gender differences emerge. Therefore, this study aimed to compare center of pressure (COP) sway variables by gender and age and to examine relationships between mean positions and other sway variables. The study included 1362 participants, including healthy males (604) and females (758) aged 20–60 years. COP sway was measured once for 1 min. As COP sway variables, the mean positions X and Y, the mean position vector R, the rectangular area, and the standard deviations X and Y were selected. R goes from the two-dimensional coordinate start point to the intersection of mean positions X and Y. Mean position X showed no large gender or age differences (partial $\eta^2 < 0.010$). In males, mean position Y was larger in the 20s, 50s, and 60s. Age difference was mainly observed in females, with the 50s and 60s tending to be larger than the 30s and 40s. The R tended to be similar to mean position Y. The unit time trajectory length, rectangular area, and standard deviations (SD) X and Y were all larger in males; in females, the degree of difference tended to be larger except for the SD Y (effect size (ES): 0.42–0.86). In any variable as a whole, the age difference was not large (partial $\eta^2 < 0.048$) but larger in the 60s than in the 20s and 30s (ES: 0.24–0.60). Correlation between mean positions X and Y was low, and both mean positions had low correlation with other sway variables. Correlation between the rectangle area and both standard deviations or between the rectangle area and the unit time trajectory length was high. The R had moderate correlation with mean position Y, but low correlation with mean position X. In conclusion, mean position X revealed no large gender or age differences. Mean positions Y and R were larger in males than in females, and age differences were found mainly in females. Mean position Y greatly affected R. Mean position X had a low relationship with mean positions Y and R, but the latter's relationship was relatively high. Both mean position variables had weak relationships with other sway variables. Mean position Y had gender and age differences similar to those of other sway variables, but mean position X did not.

Keywords: mean position, elderly, position vector

Cite This Article: Hiroki Aoki, Shinichi Demura, Shunsuke Yamaji, Yoshinori Nagasawa, and Toshiro Sato, "Comparison by Gender and Age and Their Mutual Relations with Center of Pressure Variables." *American Journal of Sports Science and Medicine*, vol. 13, no. 2 (2025): 24-29. doi: 10.12691/ajssm-13-2-1.

1. Introduction

The center of gravity sway during a human's static standing has been evaluated by using the center of pressure (COP) sway. The COP sway include the input system (inner ear, vision, and individual spinal cord receptors), reflex/control system (the central nervous system's integration and control [1]), and output system (skeletal muscles). Due to relatively high reliability of COP sway [1], variables used to evaluate them are distance (e.g., total trajectory length, sway amplitude), area (e.g., peripheral area, root mean square value area), position (e.g., mean positions of X-axis and Y-axis directions), and

variance (e.g., standard deviations of X-axis and Y-axis directions) [2,3,4,5].

The mean positions of COP's X-axis and Y-axis directions are important for evaluating postural stability [6], and their intersection is expressed in two-dimensional coordinates. We can evaluate sway position (separation) by considering both mean positions by the position vector (R) from the appliance origin point to the intersection point. Variables of distance, area, and dispersion have different characteristics than position variables [7]. Kitabayashi et al. [8] reported that in young adults, position variables showed no significant relationships with other variables.

Because COP sway's amount and pattern during static standing posture in individuals with vertigo and balance

disorders differ substantially from those in healthy individuals [9,10], they have been used clinically as a screening test. For healthy people, in contrast, COP sway has not been used as a health index, and balance ability has been assessed by applying restrictions such as eye closure and reduction of the support base to the postural control system [4,11]. During a human's standing posture, COP positions vary among individuals. For some, the COP position exists in quadrant 1 (X and Y: +); for others, in quadrant 2 (X: -, Y: +). Moreover, in some persons, the COP position sways near the stabilimeter's origin but in others, further away. In short, even if individuals stand in the same position on the stabilimeter, each COP center position differs. As stature increases with age, the center of gravity height also rises. As leg strength and balance relating to standing posture also develop with age, gender differences become marked during adolescence, but after adolescence, they decline with age.

In middle and old age, leg strength and balance ability decline markedly [12], degradation of bone and joint (e.g., deformities) progresses, and postural change occurs [13]. Therefore, the COP position is considered to differ by age and gender, but until now, whether it differs by certain ages or by gender has been little examined. Everyone's physique, posture, state of growth and development, and aging of the nervous system and motor units vary; they reflect the sway pattern, so each person has unique sway characteristics. For example, even if some persons' COP position is similarly located posteriorly, when their leg strength and balance ability in standing posture differ greatly, sway speed and range to maintain stable posture differ. Thus, if position variables differ by gender or age, variables such as distance, area, and dispersion differ accordingly, and relationships among position variables also differ. To clarify sway characteristics' interindividual variations, we must determine specific time points when age and gender differences emerge.

Therefore, this study compared COP variables according to gender and age and examined relationships between position variables and other sway variables.

2. Methods

2.1. Participants

For this study, 1,362 participants, including 602 healthy male and 758 female aged 20-60 years, had completed the morphological developmental period, with minimal variation of height and foot size, which affect COP. Table 1 displays details of their body sizes by age.

2.2. Measurement Device and Measurement Procedure

To measure COP sway, we used a stabilimeter (TAKEL, T.K.K. 5810), which can calculate the COP's center point by using vertical load sensor values installed at each vertex (4 points) of a 360-mm² board. COP data of the X-axis (right-left) direction and Y-axis (front-back) direction were recorded on a personal computer at a sampling frequency of 20 Hz. These measurements followed COP sway inspection standards [14]. Each participant closed the feet such that the center (bisector of the line from the heel to the first toe) was at the origin (0,0) on X-axis and Y-axis coordinates. Each maintained an upright posture (Romberg's Posture) and focused on a fixation point 2 m from the examination table. After confirming the hand position and posture's stability, COP sway was measured for 1 min.

2.3. COP Sway Variables

Many COP sway variables have been proposed in previous studies [2,5,7] and these variables' reliability and relationships have been examined [7]. For this study, the following variables were selected: the mean X and Y positions indicating the mean COP position along the X-axis and Y-axis coordinates, the mean speed of sway per minute (unit time trajectory length), the rectangular area indicating the magnitude of sway in the X and Y-directions (rectangular area), and the standard deviation along the X- and Y-directions (standard deviations (SD) X and Y), representing variance from the COP. In addition, the mean position vector R was calculated from the two-dimensional coordinate start point to the intersection of the mean X and Y positions (see Figure 1).

Table 1. The basic statistics for the age, height, and weight of each age group

		age(yr)		height(cm)		weight(kg)	
		Mean	SD	Mean	SD	Mean	SD
male	20s (143 people)	24.1	2.5	170.8	6.9	63.8	10.6
	30s (124 people)	34.1	2.7	172.9	5.1	67.5	11.8
	40s (116 people)	44.6	3.0	171.5	6.0	72.8	15.4
	50s (111 people)	54.5	2.5	172.8	6.3	73.3	8.8
	60s (110 people)	64.3	2.7	168.1	7.0	68.5	10.8
	total (604 people)	43.0	14.7	171.2	6.5	68.9	12.2
female	20s (151 people)	23.7	2.4	158.2	5.3	51.8	8.0
	30s (223 people)	34.2	2.7	159.0	5.3	51.8	7.1
	40s (168 people)	44.8	2.5	158.5	5.9	54.7	8.4
	50s (101 people)	53.8	3.3	159.1	4.6	54.1	8.5
	60s (115 people)	64.6	2.3	156.2	4.6	52.8	6.9
	total (758 people)	41.7	13.7	158.3	5.3	52.9	7.8

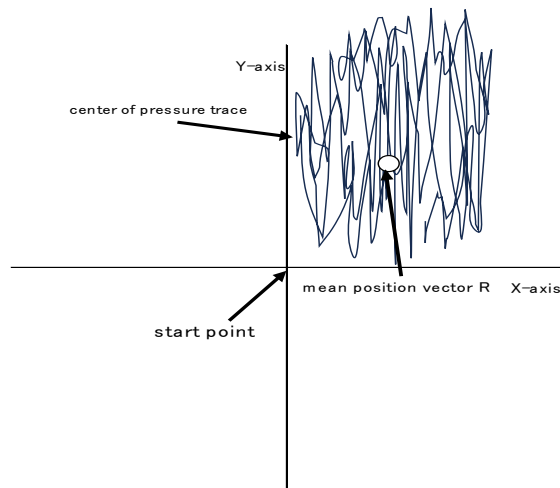


Figure 1. Image of the R

2.4. Statistical Analyses

Analysis of variance (two-way non-repeated measures ANOVA) was used to examine age and gender differences in the evaluation variables' mean values. When significant interactions or main effects were detected, multiple comparison tests were performed using Tukey's honestly significant difference method. Effect size (partial η^2) was interpreted as follows: 0.01 (small), 0.06 (medium), and 0.14 (large). Additionally, the effect size (ES: Cohen's d) of the mean difference between the two groups was classified as 0.2-0.5 (small), 0.5-0.8 (moderate), and ≥ 0.8 (large) [15]. Relations among COP sway variables were examined by Pearson's correlation, classified as low (0.2-0.4), moderate (0.4-0.7), and high (≥ 0.7). A significance level of 5% ($p < 0.05$) was used throughout the study.

3. Results

Table 2.1 shows basic statistics by gender and age, and results of the two-way ANOVA (gender $\times$ age) for mean positions X and Y, and R. Mean position X showed a significant main effect only in the gender factor, and mean positions Y and R showed a significant interaction effect,

but the effect sizes were not large (partial η^2 : 0.010–0.038). Mean position Y had negative value in both genders, and comparison results showed moderate (ES: 0.57–0.75) gender differences in the 20s, 50s, and 60s. For males, an age-level difference was found between means in the 40s and in the 20s and 50s (ES: 0.46–0.49), and for females, between means in the 60s and in the 20s, 30s, and 40s and between means in the 50s and in the 30s and 40s. Their ES was moderate (0.48–0.74). The R showed significant gender differences (ES: 0.37–0.44) in the 40s and 60s. For males, an age-level difference was found between means in the 40s and 20s and 30s and for females, between means in the 60s and in the 20s, 30s, and 40s. Their ES was moderate (0.50–0.56) except for males between the 40s and 30s.

Table 2.2 displays basic statistics by gender and age and two-way ANOVA results for the unit time length, rectangular area, and standard deviations X and Y. No variables showed significant interaction, but both gender and age factors showed significant main effects. Gender differences' effect sizes were moderate (partial η^2 : 0.059–0.092) in unit time length, rectangular area, and SD X. However, the gender difference's effect sizes in SD Y and age differences in all variables were small (partial η^2 : 0.009–0.048). In multiple comparisons, the unit time length showed moderate (ES: 0.61–0.86) gender difference in all age groups except the 60s. An age-level difference was found between means in the 20s and 30s and in the 40s, 50s, and 60s. The ES between means in the 60s and in the 20s and 30s (0.56–0.60) was moderate. The rectangular area showed gender differences in the 20s, 30s, 40s, and 60s, and their ES was moderate (0.47–0.72). An age-level difference was shown between means in the 60s and in the 20s, 30s, 40s, and 50s and between means in the 30s and 50s. Their ES (0.50–0.59) was moderate. The SD X showed moderate significant gender differences (ES: 0.42–0.68) in the 20s, 30s, 40s, and 60s. An age-level difference was found between means in the 60s and in the 20s, 30s, and 40s, but their ES was not large (0.27–0.42). The SD Y showed significant gender differences in the 20s and 60s (ES: 0.34–0.46), and an age-level difference was found between means in the 60s and in the 20s, 30s and 40s, but their ES was not large (0.24–0.30).

Table 2.1. Basic statistics by gender and age, and results of the Two-way ANOVA for the mean positions X and Y, and R

	mean positions X		mean positions Y		R								
	Mean	SD	Mean	SD	Mean	SD	ANOVA						
male							F1	partial η^2	F2	partial η^2	F3	partial η^2	
20 s	3.4	10.9	-5.9	19.6	19.4	13.2	mean positions X	13.486*	0.010	2.006	0.006	1.759	0.005
30 s	4.0	8.1	-11.1	21.9	21.0	15.4	mean positions Y	21.552*	0.015	7.313*	0.020	13.723*	0.038
40 s	1.7	15.1	-18.3	29.6	29.2	24.3	R	1.540	0.001	8.084*	0.023	6.952*	0.020
50 s	2.9	13.6	-5.6	25.3	23.8	17.1	Post-hoc						
60 s	2.3	10.5	-13.4	24.3	24.0	17.6	mean positions X	gender	male>female(50s(0.38))				
total	2.9	11.8	-10.7	24.5	23.2	18.0	mean positions Y	gender	20s(0.57), 50s(0.75), 60s(0.57): male>female				
female							age	male: 20s(0.46), 50s(0.49)<40s					
20 s	2.7	8.5	-17.0	19.1	21.6	16.2		female: 20s(0.48), 30s(0.62), 40s(0.74)<60s; 30s(0.49), 40s(0.62)<50s					
30 s	0.2	10.2	-11.8	26.0	21.7	21.2	R	gender	40s: male>female(0.37); 60s: male<female(0.44)				
40 s	0.1	11.6	-9.1	24.4	21.1	19.1	age	male: 20s(0.50), 30s(0.40)<40s					
50 s	-2.2	13.1	-23.7	22.7	28.2	21.4		female: 20s(0.56), 30s(0.50), 40s(0.55)<60s					
60 s	1.6	14.7	-28.4	27.8	33.6	25.9							
total	0.6	11.5	-16.3	25.2	24.2	21.1							

* $p < 0.05$; F1: gender difference(gender), F2: age difference(age), F3: interactions; (): ES

Table 2.2. Basic statistics by gender and age, and results of the Two-way ANOVA for the unit time length, rectangular area, and standard deviations X and Y

unit time trajectory length		rectangular area		SDX		SDY		ANOVA							
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		F1	partial η^2	F2	partial η^2	F3	partial η^2
male															
									unit time trajectory length	136.518*	0.092	16.878*	0.048	1.766	0.005
2 0 s	7.8	2.4	487.1	268.4	3.8	1.4	4.7	1.7	rectangular area	96.232*	0.066	13.570*	0.039	2.247	0.007
3 0 s	8.0	3.1	475.3	251.7	3.7	1.2	4.8	1.8	SDX	85.280*	0.059	6.143*	0.018	1.313	0.004
4 0 s	9.4	3.6	569.9	332.2	4.1	1.4	4.7	1.7	SDY	39.866*	0.029	3.171*	0.009	0.471	0.001
5 0 s	9.0	3.6	527.4	303.9	3.9	1.5	4.7	1.6							
6 0 s	9.7	3.9	691.1	379.5	4.4	1.7	5.3	1.7	Post-hoc						
total	8.7	3.4	545.1	315.7	4.0	1.5	4.8	1.7	unit time trajectory length	gender male>female(20s(0.61), 30s(0.65), 40s(0.86), 50s(0.61), 60s(0.44))					
female															
									age	20s<40s(0.27), 50s(0.36), 60s(0.56); 30s<40s(0.32), 50s(0.41), 60s(0.60)					
2 0 s	6.4	2.4	365.7	245.6	3.2	1.2	4.2	1.7	rectangular area	gender male>female(20s(0.47), 30s(0.48), 40s(0.72), 60s(0.63))					
3 0 s	6.3	2.2	360.8	225.1	3.2	1.3	4.2	1.5	age	20s(0.50), 30s(0.59), 40s(0.40), 50s(0.31)<60s; 30s<50s(0.28)					
4 0 s	6.8	2.4	368.2	216.4	3.2	1.3	4.2	1.6	SDX	gender male>female(20s(0.53), 30s(0.42), 40s(0.68), 60s(0.53))					
5 0 s	7.1	2.2	423.1	301.6	3.4	1.2	4.2	2.0	age	20s(0.34), 30s(0.42), 40s(0.27)<60s					
6 0 s	8.0	3.4	476.3	298.1	3.6	1.5	4.5	1.9	SDY	gender male>female(20s(0.34), 60s(0.46))					
total	6.8	2.6	389.2	253.6	3.3	1.3	4.2	1.7	age	20s(0.24), 30s(0.26), 40s(0.30)<60s					
*p<0.05; F1: gender difference(gender), F2: age difference(age), F3: interactions; (): ES															

*p<0.05; F1: gender difference(gender), F2: age difference(age), F3: interactions; (): ES

Table 3. Correlations among sway variables and age

	mean positions X	mean positions Y	unit time trajectory length	rectangular area	SDX	SDY	age
mean positions X							-0.05
mean positions Y	0.16*						-0.11*
unit time trajectory length	-0.01	-0.10*					0.22*
rectangular area	-0.05	-0.14*	0.69*				0.19*
SDX	-0.02	-0.11*	0.59*	0.83*			0.13*
SDY	-0.05	-0.09*	0.42*	0.74*	0.49*		0.08*
R	-0.13*	-0.62*	0.31*	0.25*	0.22*	0.19*	0.15*

*p<0.05

Table 3 displays correlations among age and sway variables, all of which had low correlations ($r < 0.218$) with age. Mean positions Y and R showed moderate correlation (-0.62), but the mean X position had low correlations (-0.13–0.16) with them. Mean positions Y and R showed low and significant correlations with unit time length, rectangular area, and SD X and Y (r : -0.09–0.31). The rectangular area showed high correlations (r : 0.74 and 0.83) with SD X and Y, but the unit time length showed them from 0.42 to 0.69 with the rectangular area and the SD X and Y.

4. Discussion

Mean position X evaluates the left–right direction's sway position, with a positive value for right-foot loading and a negative value for left-foot loading. In contrast, mean position Y evaluates the before–after direction's sway position, with a positive value for toe load and a negative value for heel load. In these results, mean position X was positive (except for some ages), while mean position Y was negative for all ages. Moreover, Ogaya et al. [16] reported that mean position Y was negative in both adolescents and older adults.

Mean position X showed no large gender or age differences (partial $\eta^2 < 0.010$). In males, mean position Y was larger (20s, 50s, and 60s) age differences were found mainly in females, and the 50s and 60s tended to have larger differences than the 30s and 40s. For young people and for older adults, Kitabayashi et al. [17] and Wiśniowska-Szurlej et al. [18] respectively reported that the gender difference was not in the mean position. Indeed, our results are largely consistent with those in previous

reports. The elderly's center of gravity shifts backward [19], and from our results, we can infer that particularly middle-aged and older women's central position is located posteriorly, and the gender difference becomes more pronounced. Position vector R, from the origin to the intersection of mean positions X and Y, tended to be similar to mean position Y. We inferred that the sway position is more distant from the origin, and mean position Y more greatly affects the R of older adults than of other age groups.

The unit time trajectory length, rectangular area, and standard deviations X and Y were all larger in males than in females, and the degree of difference tended to be larger except for the standard deviation Y (ES:0.42~0.86). The unit time trajectory length evaluates sway velocity, the rectangular area determines the sway's size, and the standard deviations X and Y are variables related to the sway's variance. Until now, studies have reported that gender differences exist in these variables [20]. These results indicate that gender differences in sway's speed, magnitude, and lateral dispersion are relatively large.

On the other hand, for any variable as a whole, age differences were not large but tended to be larger in the 60s than in the 20s and 30s (ES:0.24~0.60). Demura et al. [21] similarly reported that variables related to speed and area are greater in older adults than in younger people. In old age, leg strength and balance ability decline rapidly [12], bone and joints' aging progresses (degenerative change), and standing posture also changes [13]. Thus, to maintain stable posture, older adults may have faster and larger sway than youth.

All variables had a low relationship with age, and the relationship between mean positions X and Y was also low. Furthermore, Goldie et al. [22] reported no

significant correlation between center positions of the X-axis and Y-axis. Despite variables having the same position, they might still have different characteristics. Unlike the relationship between the rectangle area and both standard deviations, or between the rectangle area and the unit time trajectory length, the mean position had a low relationship with other sway variables. These results were also consistent with those in Demura et al. [7]. The mean position is affected by the foot-ground position, foot size, and load (toe load, heel load), but the sway's speed, magnitude, and dispersion are completely unaffected by the foot-ground position [20].

On the other hand, if the left-right and anteroposterior sways are larger, the sway's distance, area, and dispersion are larger, leading to increases in their relationships. Mean positions X and Y were suggested to have different sway characteristics from the velocity, area, and dispersion variables. R represents magnitude from the origin to the intersection of the mean positions X and Y. Presumably, it has high relationships with both mean positions, but low with mean position X. The mean of the overall mean position X was close to the origin in both genders (2.9 for males, 0.6 for females), but the mean of the mean position Y was far from the origin (-10.7 for males, -16.3 for females). The R is judged to be largely influenced by the mean position Y.

These results indicate that mean positions X and Y have different sway characteristics from variables related to velocity, area, and dispersion and that R is more influenced by the mean position Y. Mean position X showed no significant gender and age differences. These results differed from those for other sway variables (i.e., unit time trajectory length, rectangular area, standard deviations X and Y). Left and right loads greatly affect mean position X. That the legs' musculature is involved in the load's exertion has been clarified [23]. In daily life, the legs perform little unilateral weight-bearing movement, and leg strength's left-right difference is small [24]. Therefore, the left-right difference is low; hence, the small SD X for evaluating left-right sway might not be due to gender or age differences.

Mean position Y showed gender and age differences like those of other sway variables, but the degree was not large. Older adults are also thought to have decreased posture control due to, among other factors, decreased muscle strength and balance ability [12] and postural changes [13]. Additionally, according to the influencing factors above, their center of gravity shifts backward [19]. In this study, however, older adult females exhibited a more posterior position than other age groups. Possibly, older adults' (particularly older adult females') decreased ability to control their posture affected each variable's gender and age differences.

5. Conclusion

This study examined gender and age differences of COP sway variables (mean positions X, Y, and R, unit time trajectory length, rectangular area, and standard deviations X and Y) and relationships between mean position variables and other sway variables. Given the participants' limitations, the variables, the analytical

method, and so on, the following were found.

1. Mean position X showed no large gender or age differences.
2. Mean positions Y and R were larger in males than in females, and age differences were mainly observed in females.
3. R was greatly affected by mean position Y.
4. Mean position X had weak relationships with mean positions Y and R, but Y and R's relationship was relatively high.
5. The mean position variables had weak relationships with the unit time trajectory length, rectangular area, and both standard deviations.
6. Mean position Y had gender and age differences similar to those of other sway variables, but mean position X did not.

ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Number 18K11097

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