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Statistical analysis on multi-factors of dynamic plantar pressure to normal subjects

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ABSTRACT

Plantar pressure analysis has been found effective in many fields, such as rehabilitation evaluation, footwear design, nervous system disease analysis, etc. Plantar pressure features may be affected by many factors, such as age, gender, weight, etc., which cannot be ignored in related research and applications. Our research focuses on normal groups, mainly analyzes the differences between different age and gender groups, and considers the influence of height, weight, shoe size, and body mass index (BMI). Measured by a dynamic plantar pressure system, the plantar pressure data of the subjects in walking and standing states are analyzed. Through analysis by statistics and regression methods, we draw the following main conclusions: (1) there are obvious differences between young and old groups in static features, reflecting the impact of age on human balance; (2) the difference between men and women is more in the pressure distribution of the plantar region, especially in the metatarsal region, reflecting the difference in the physiological structure caused by gender; (3) it is also found that height, weight, shoe size and BMI have certain effects.

1. Introduction

Plantar pressure is important for understanding gait mechanics [1–4]. The plantar pressure distribution pattern can reflect the biomechanical condition of the foot, that has been widely used in the diagnosis of human health problems [5,6]. At present, the analysis technology for plantar pressure mainly uses the plantar pressure plate or pressure insole for data collection [7,8]. Plantar pressure analysis based on plantar pressure measurement system can be used to distinguish normal gait from pathological gait, design foot orthoses, predict risk factors for lower extremity injuries, assess disease progression, evaluate treatment effects, footwear design, etc [9–11]. However, in reality, there are many factors that can directly or indirectly affect plantar pressure, such as disease status, age, gender, body mass index (BMI), etc [12]. In practical application scenarios, these factors cannot often be ignored. Moreover, different factors have different effects on plantar pressure. Studying the influence of these factors on plantar pressure has certain reference significance for the research and application of plantar pressure.

In previous studies, the influence of age, gender and other population characteristics on the features of plantar pressure was often taken as the object of analysis. Kwan et al. measured the stiffness and thickness of soft tissue in various regions of the plantar and studied their correlation with age [13]. Lee et al. used the multi-segment foot model (MFM) to extract the angle of each segment of the foot during motion as features, and studied the differences between men and women from a kinematic perspective [14]. The above literature studied the differences caused by age and gender from the perspective of biological structure and kinematics, and reflected the biomechanical properties of the human body in an indirect way. Khalaf et al. extracted the GaitEn feature based on plantar pressure data, compared between the overweight group and the normal group, and studied the influence of BMI on plantar pressure [15]. Some studies discuss the effects of both age and gender. Demirbüken et al. took adolescents as research objects and used statistical analysis methods to study the effects of gender and age on the features of plantar pressure [16]. Gimunová et al. divided the control group according to age and gender for the elderly group, and calculated the effect size to reflect the influence of age and gender on each feature [17]. These studies take a specific population as the research object, thus resulting in a concentrated sample distribution.

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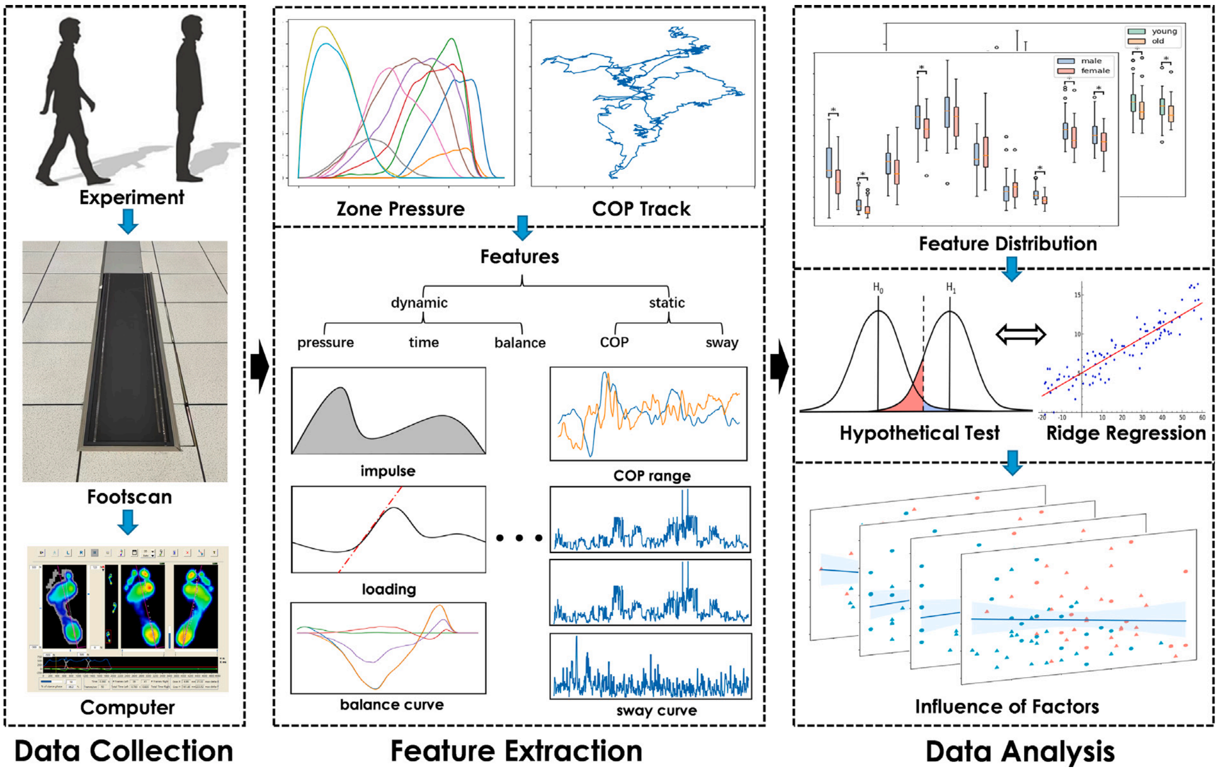

Fig. 1. Overall process of dynamic plantar pressure analysis.

There are also some studies that consider multiple factors for analysis. Mei et al. study the differences between different foot type groups, and calculated the sample entropy of the parameters related to the center of pressure during walking as features for comparison, while considering the influence of data length, weight, age, height, gender, and shoe size on the features, and analyzed the influence of these variables using between-subject effect test [18]. This study comprehensively considered the influence of multiple factors, but the features and analysis methods used are relatively single, lacking in-depth discussion. Aiming at the analysis of male subjects with different weights, Hue et al. extracted features reflecting the human balance control ability based on the center of pressure, and analyzed the influence of weight, height, age, and foot length on the static balance features by regression analysis method [19]. This study conducted a multivariate analysis, but was limited to males, and the age distribution of the subjects was not large enough to reflect differences.

At present, there have few studies on the influence of population characteristics on the features of plantar pressure. Currently, the most commonly used are features related to plantar pressure in dynamic processes, while the features reflecting spatiotemporal parameters, human balance and other aspects are rarely used. And most of the studies are analyzed from the perspective of groups, individual differences are rarely considered, and there is a lack of analysis studies for the mixed effects of multiple factors.

In this paper, we studied the effects of age, gender, and other multi-factors on plantar pressure features in normal subjects. We collected dynamic and static pressure data from 76 normal subjects, as well as the information on their population (including age, gender, height, weight, shoe size). Based on the pressure data, pressure-related features, time-related features, balance-related features, center of pressure (COP) related features and sway-related features were extracted. We firstly conducted a group comparison analysis between the youth group and the old group, the male group and the female group, and analyzed the differences in the features of plantar pressure caused by age and gender through the statistical analysis method. Afterwards, a ridge regression method was used to further explore the effects of age and gender. Height, weight, shoe size, and body mass index were also included in the model for consideration, and the influence of each factor on the plantar pressure features was analyzed. The results of statistical and regression analyses are compared and verified, which makes the final conclusion more reliable. Fig. 1 shows the overall flowchart of the work.

The main contributions of our research are as follows: (1) We comprehensively study many features that can reflect mechanical properties, pressure distribution, spatiotemporal parameters, human body balance, etc., so as to provide a data processing method for plantar pressure. It is helpful to understand the information of plantar pressure; (2) Through statistics and regression analysis, we have shown the influence of individual factors such as gender and age on plantar pressure, and clarified the degree of these influences in various features, which have certain reference value for related research and application.

2. Methods

2.1. Participants

A total of 76 healthy subjects were recruited to participate in the experiment, and all subjects understood the experimental content and signed the informed consent. In order to ensure that the age distribution of the samples has a certain difference, the subjects are required to be either younger than 30 years old or older than 50 years old, thus forming a youth group and an elderly group. The final analysis contains 48 young subjects and 28 elderly subjects. These data are also divided into two control groups by gender, with 39 males and 37 females. Before analysis, the health status of each subject is investigated, excluding subjects who had difficulty in walking, motor system diseases or other foot diseases. Physical characteristics of all subjects are recorded (including age, gender, height, weight, shoe size). The demographic characteristics of participants are listed in Table 1.

Table 1
Demographics of subjects in different groups.

Group		N	Age (yeas)	Height (cm)	Weight (kg)	Shoe szie (cm)	BMI (kg/m^2)
			mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD
Young	male	27	23.37 ± 1.97	175.11 ± 4.92	65.87 ± 9.28	25.78 ± 0.66	21.46 ± 2.72
	female	21	25.33 ± 2.59	164.05 ± 5.36	54.93 ± 8.70	23.71 ± 0.63	20.39 ± 3.02
Old	male	12	56.17 ± 4.18	170.00 ± 5.90	68.17 ± 11.33	25.42 ± 0.79	23.57 ± 3.69
	female	16	52.81 ± 4.48	155.88 ± 5.45	58.50 ± 8.09	23.38 ± 0.67	24.08 ± 3.18
Total		76	35.29 ± 14.88	167.20 ± 9.03	61.66 ± 10.64	24.65 ± 1.26	22.05 ± 3.40

BMI: body mass index; SD: standard deviation.

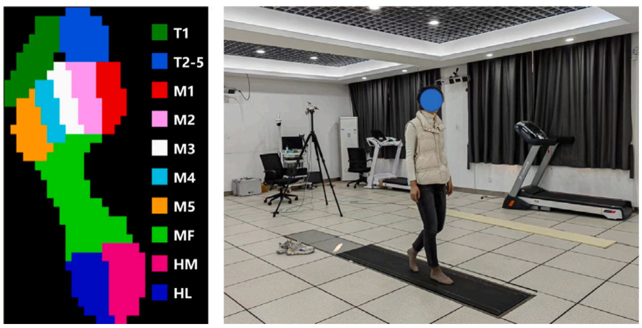

Fig. 2. Ten plantar zones divided by software and Data collection experiment in the laboratory.

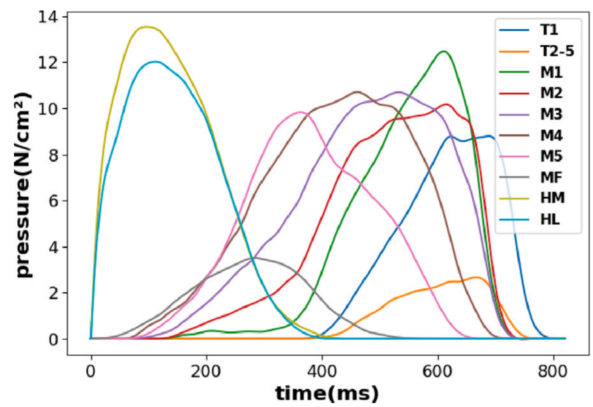

Fig. 3. An example of pressure curves for ten zones.

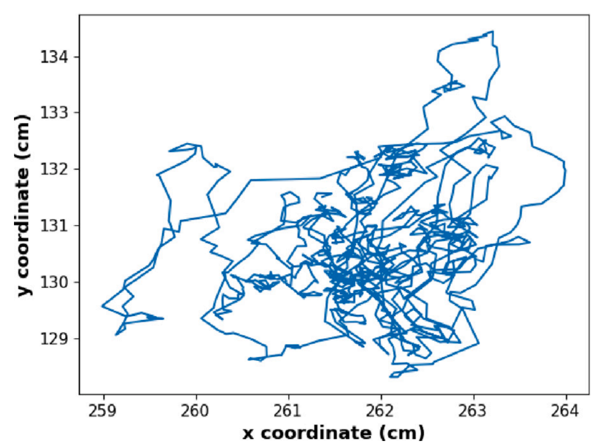

Fig. 4. An example of the COP trajectory.

2.2. Data collection

In our study, a novel plantar pressure measurement system (RSs-can International, Olen, Belgium, shown in Fig. 2) is used for data collection, which includes a 2-m pressure measuring plate, containing 8192 resistance sensors (4 sensors/cm^2) with the sampling frequency of 50 Hz. Combined with the corresponding data processing software, the dynamic and static plantar pressure data can be measured and analyzed separately.

Two experiments are designed: (1) dynamic analysis and (2) static analysis. In the dynamic experiment, the subjects walked at a normal speed and walked over the pressure measurement plate. Each subject will repeat the walking 5 times to complete data collections. In the static experiment, the subjects maintained a natural standing state in the measuring plate area with their eyes open and closed respectively. Each subject continued for a certain period of time and the data recording duration is 20 s.

2.3. Data preprocessing

After software processing, the dynamic data is the sequence of the pressure of 10 plantar zones, namely are: first toe (T1), second to fifth toes (T2-5), first metatarsal (M1), second metatarsal (M2), third metatarsal (M3), fourth metatarsal (M4), fifth metatarsal (M5), midfoot (MF), heel medial (HM), heel lateral (HL), as shown in Fig. 2. Fig. 3 shows an example of the pressure curves of 10 zones. The static data is the time varying sequence of the plantar pressure center coordinates, including the horizontal and vertical coordinates. The movement of the COP on the plane can be decomposed into horizontal and vertical directions, and then use x to represent the horizontal direction and y to represent the vertical direction. Fig. 4 gives an example of the COP trajectory.

Since dynamic data is obtained by repeated measurement, the consistency degree of repeated measurement data is analyzed for dynamic data. The dynamic data for each measurement is a discrete sequence of pressure values over time. The Fréchet distance is used to compare the similarity between two discrete sequences of unequal length [20]. For each measurement data, the Fréchet distance is calculated with others and the sum is accumulated, which is used to characterize the degree of consistency of the measurement data relative to the whole. Among the 5 measurements, three with better consistency were selected for subsequent analysis. The Fréchet distance is derived by

$$F(A,B) = \inf_{\alpha,\beta} \max_{t\in[0,1]} \{d(A(\alpha(t)), B(\beta(t)))\} \tag{1}$$

where A and B are the curves on the metric space, α and β are two reparameterized functions of [0, 1], d is the distance function on the metric space.

In addition, Pearson correlation coefficient [21] was used to calculate the correlation between left and right foot data for each subject. Since in this study, the data are all from healthy subjects, the left and right foot data generally have a high correlation, so the subsequent analysis will not make a distinction between them. The Pearson correlation coefficient is derived by

$$\rho_{X,Y} = \frac{cov(X,Y)}{\sigma_X\sigma_Y} = \frac{E\left[(X-\mu_X)(Y-\mu_Y)\right]}{\sigma_X\sigma_Y} \tag{2}$$

Table 2
All extracted features.

Dynamic features	pressure-related	pressure peak of each zone impulse of each zone loading of each zone
	time-related	peak time of each zone contact time of each zone phase percentage
	balance-related	foot balance forefoot balance heel rotation medial forefoot balance metatarsal loading (peak, mean, SD)
Static features	COP-related	displacement range ellipse area velocity RMS acceleration RMS acceleration RMS SampEn of velocity
	sway-related	sway density sway length sway radius (peak, mean, SD)

COP: center of pressure; RMS: root mean square; SD: standard deviation; SampEn: sample entropy.

where cov is the correlated standard deviation, σ_X and σ_Y are the standard deviations of X and Y, μ_X and μ_Y are the mean of X and Y, and E denotes the expectation.

2.4. Feature extraction

For plantar pressure characterization, the pressure-related, time-related, and balance-related features are calculated for dynamic experiment. Dynamic features are calculated based on data within a stance phase. The stance phase is the duration of a single foot from touching the ground to completely leaving the ground [22]. The median calculated from multiple measurements is taken as the features of a sample. Static features are divided into two categories: COP-related and sway-related features. The static features in the open-eye state and the closed-eye state are calculated separately. All the features are shown in the Table 2, which will be introduced in detail subsequently.

2.4.1. Pressure-related features

The pressure peak represents the maximum pressure in the plantar zone. Impulse is the integral of zone pressure over time. The load rate is the maximum value of the rate of change when the pressure increases. Since pressure-related features are closely related to body weight, these features are calculated through dividing by the weight of the subject to reduce the effect of weight in the statistical analysis.

2.4.2. Time-related features

The peak time is the time when the pressure peak of the zone appears. The contact time is the total time that the zone touches the ground. A stance phase can be divided into four phases: the initial contact phase (ICP), the forefoot contact phase (FFCP), the foot flat phase (FFP), and the forefoot push off phase (FFPOP). The duration of each phase is calculated as a feature for characterization. Time-related features are divided by the subject's stance phase duration and expressed as a percentage.

2.4.3. Balance-related features

To reflect the balance performance during walking, the pressures of different zones are subtracted from each other to obtain the pressure balance curves. Particularly, the following pressure balance curves are calculated: foot balance, forefoot balance, heel rotation, medial forefoot balance, metatarsal loading, as detailed in Table 3. Further, the peak, mean, and standard deviation (SD) on these pressure balance curves are derived.

Table 3
Calculation formulas for balance-related features.

Balance curve	Formula
Foot balance	(M1+M2+HM) - (M3+M4+M5+HL)
Forefoot balance	(M1+M2) - (M3+M4+M5)
Heel rotation	HM - HL
Medial forefoot balance	M2 - M1
Metatarsal loading	(M2+M3) - (M1+M4+M5)

2.4.4. COP-related features

Based on the COP data measured by static experiments, features reflecting static balance are calculated [23]. For the pressure center coordinate change curve, the x and y movement range and the confidence ellipse area (referring to the area including 95% of the pressure center trajectory) are calculated. These features mainly quantify the movement range of COP, and the larger the range, the more obvious the human body swings. In addition, the change curves of COP moving speed and acceleration (including x direction, y direction, combined direction) are extracted. The root mean square (RMS) is also calculated as features. The larger the value, the more violent the human body swing. Finally, the sample entropy [24] of the coordinate change curve and the speed change curve are calculated respectively, which represents the chaotic degree of COP change.

The definition of sample entropy (SampEn) is given below. For a given sequence $N = \{x_1, x_2, x_3, \dots, x_N\}$, constructs a template vector of length m such that $X_m(i) = \{x_i, x_{i+1}, x_{i+2}, \dots, x_{i+m-1}\}$. Define $d\left[X_m(i), X_m(j)\right]$ as the absolute value of the maximum difference between the corresponding elements of X and Y, SampEn is derived by

$$\mathrm{SampEn} = -\ln\frac{A}{B} \tag{3}$$

where A is the number of template vector pairs having $d\left[X_{m+1}(i), X_{m+1}(j)\right]$, B is the number of template vector pairs having $d\left[X_m(i), X_m(j)\right]$.

2.4.5. Sway-related features

For the COP trajectory, some sway curves are further extracted to calculate features reflecting the degree of human body sway [25]. A circle with a fixed radius is firstly determined, and then moving the circle along with the COP trajectory. The number of samples falling into the circle at each moment is counted to obtain the sway density curve. The length of the COP trajectory falling into the circle at each moment is counted to obtain the sway length curve. The larger these values are, the smaller the span of the moving range of the COP trajectory is, and the more stable the human body will be. In addition, a fixed time window is determined to slide with the COP trajectory. For the COP trajectory in each time window, the minimum radius of the circle that can contain the COP trajectory is calculated, and all sampling points are counted to obtain the sway radius curve. The larger the value, the more obvious the human body swings. Based on these sway curves, the peak, mean, and standard deviation (SD) are finally calculated as features to reflect the stability of the human body in a static state.

2.5. Statistical analysis

In this study, the comparison groups were divided according to age and gender, and statistical methods were used to analyze the differences in the features of plantar pressure in different groups. For each group, the Shapiro–Wilk test was used to verify the normal distribution of features. For the features that conform to the normal distribution, the independent sample t-test is used to analyze the differences between groups [26–30], calculated as

$$t = \frac{\overline{X} - \overline{Y}}{\sqrt{\frac{S_1^2}{n} + \frac{S_2^2}{m}}} \tag{4}$$

where S_i^2 is the unbiased estimator of the standard deviation of each of the two samples.

For the features that do not conform to the normal distribution, the Mann–Whitney U-test is used to analyze the differences between groups, defined as

$$U = \sum_{i=1}^{n} \sum_{j=1}^{m} S\left(X_i, Y_j\right) \tag{5}$$

with

$$S(X,Y) = \begin{cases} 1, & \text{if } X > Y, \\ \frac{1}{2}, & \text{if } X = Y, \\ 0, & \text{if } X < Y. \end{cases} \tag{6}$$

In addition, in this part, we mainly focus on studying the differences between groups according to a single factor. The interaction between age and gender is not considered in this section, and this issue will be discussed and analyzed in the next section.

2.6. Regression analysis

Considering the influence of multiple factors, including: age, gender, height, weight, shoe size, regression methods are applied to analyze their effects on foot pressure features. In the regression model, the age, gender, height, weight, and shoe size are set to independent variables, as well as each feature. Among them, age and gender were set as dummy variables, we set youth to 0, old to 1, male to 0, and female to 1. All variables are standardized.

Due to the high correlation between the various independent variables, there is a multicollinearity problem [31]. In a general linear regression model, variables that are correlated with each other are added to the model, which will interfere with each other, resulting in inaccurate results. To solve the problem, ridge regression method was used for the analysis. It is a multiple regression method suitable for scenarios where independent variables are highly correlated with each other [32]. It can remove the effect of multicollinearity and make the regression coefficients more reliable.

For a linear regression

$$y = \sum_{j=1}^{p} \beta_j x_j + \beta_0 \tag{7}$$

the objective function for ridge regression is

$$\hat{\beta} = \underset{\beta}{\operatorname{argmin}} \left\{ \sum_{i=1}^{N} \left(y_i - \beta_0 - \sum_{j=1}^{p} \beta_j x_i \right)^2 + k \sum_{j=1}^{p} \beta_j^2 \right\} \tag{8}$$

where β is the regression coefficient, k is the ridge parameter.

Ridge regression is a modified least squares method that introduces a regularization term with a coefficient of k in optimization. Here, k determines how to adjust the coefficients. Ridge trace graph [33] is used to select k. The curve of each standardized regression coefficient changing with k value is given. The minimum k value when the standardized regression coefficients of all independent variables tend to be stable will be selected. Fig. 5 gives an example on k selection. The ridge trace of a certain feature is depicted. It can be found that when $k \geq 0.4$, the changes of all regression coefficients tend to be stable.

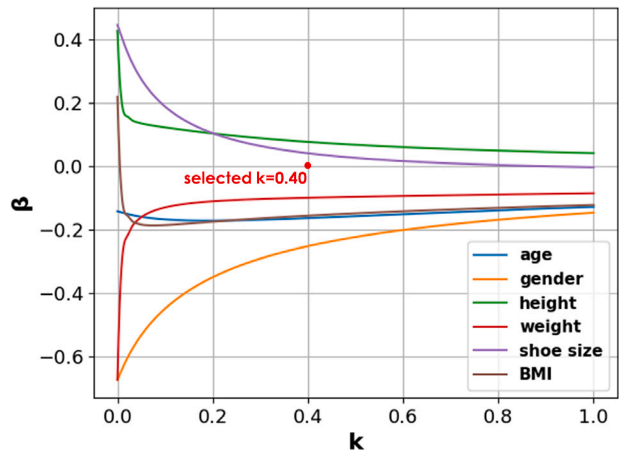

Fig. 5. Ridge parameter selection.

3. Results

3.1. Comparison between different groups

The first experiment studies the plantar pressure difference and affection to different groups: including comparisons between youth and old age group, male and female group, respectively. The difference analysis on each group is conducted on pressure-related, time-related, balance-related, and static plantar pressure features respectively in the following.

3.1.1. Differences in pressure-related features

Table 4 shows the statistical results of pressure-related features in two different groups. For the peak pressure of each zone, the young group was significantly higher than the old group in T1, HM, and HL zones, and significantly lower than the old group in M5, MF zones. For the impulse of each zone, the impulse in the T1 zone of the young group was significantly higher than that of the old group, while the impulse of the M3, M5 and MF zones were significantly lower than those of the old group. For the loading of each zone, the young group and the old group had significant differences only in the T1 zone. By comparisons, it was found that the peak pressure and impulse in the heel region of the young group were significantly higher than those of the old group, while the peak pressure and impulse in the middle region were significantly lower than those in the old group, indicating the main bearing parts of the feet of different age groups had certain differences.

The peak pressure in T1, T2-5, M2, MF, HM, HL zones of male and female groups were significantly different, and the male group was significantly higher than the female group. For the impulse of each zone, the values of the male group were significantly higher than those of the female group in the T1, T2-5, and MF zones; The loading in the T1, T2-5, M2, M3, MF, and HM zones of the male group were significantly higher than those of the female group. It can be found that most of the pressure-related features are higher in the male group than in the female group, which may be caused by the difference in weight and body shape between the male and female groups.

3.1.2. Differences in time-related features

Table 5 shows the statistical results of time-related features in different groups. For the time-related features of each zone, there were few differences between the young group and the old group, only the contact time of M5 zone, the peak time in T1 and T2-5 zones, and the duration of ICP had significant differences. The peak time in M1, M2 and M3 zones of male group was significantly lower than those in female group, and the peak time in HM zone was significantly higher

Table 4
Significance statistics of pressure-related features in age group and gender group.

Features	Age				Gender			
	Young	Old	F	p	Male	Female	F	p
pressure peak_T1	0.12 ± 0.05	0.09 ± 0.05	0.39	**0.03**	0.12 ± 0.05	0.09 ± 0.04	2.25	**0.01**
pressure peak_T2–5	0.03 ± 0.02	0.03 ± 0.02	0.45	0.99	0.03 ± 0.02	0.02 ± 0.02	0.94	**0.00**
pressure peak_M1	0.13 ± 0.04	0.12 ± 0.04	0.20	0.49	0.13 ± 0.04	0.12 ± 0.05	1.88	0.13
pressure peak_M2	0.24 ± 0.04	0.22 ± 0.04	0.00	0.14	0.25 ± 0.05	0.22 ± 0.04	1.28	**0.00**
pressure peak_M3	0.26 ± 0.06	0.24 ± 0.05	0.07	0.10	0.26 ± 0.06	0.24 ± 0.05	0.60	0.15
pressure peak_M4	0.16 ± 0.06	0.15 ± 0.04	2.07	0.75	0.15 ± 0.04	0.16 ± 0.06	3.39	0.12
pressure peak_M5	0.06 ± 0.02	0.08 ± 0.04	1.90	0.07	0.07 ± 0.04	0.07 ± 0.03	0.85	0.11
pressure peak_MF	0.05 ± 0.01	0.06 ± 0.02	3.27	**0.01**	0.06 ± 0.02	0.04 ± 0.01	1.18	**0.00**
pressure peak_HM	0.21 ± 0.04	0.20 ± 0.04	0.00	**0.02**	0.22 ± 0.04	0.20 ± 0.04	0.02	**0.01**
pressure peak_HL	0.20 ± 0.03	0.18 ± 0.03	0.34	**0.01**	0.20 ± 0.03	0.18 ± 0.03	0.13	**0.01**
impulse_T1	23.77 ± 11.87	17.89 ± 10.59	0.08	**0.04**	25.03 ± 12.26	18.35 ± 10.26	1.12	**0.01**
impulse_T2–5	4.65 ± 3.54	4.57 ± 3.34	0.31	0.94	5.68 ± 3.60	3.62 ± 3.02	1.01	**0.00**
impulse_M1	29.74 ± 11.13	27.39 ± 13.06	0.06	0.19	29.83 ± 9.66	27.97 ± 13.69	2.90	0.22
impulse_M2	63.59 ± 13.62	58.47 ± 13.94	0.02	0.13	63.80 ± 14.10	59.71 ± 13.53	0.19	0.21
impulse_M3	74.17 ± 16.59	65.46 ± 17.06	0.70	**0.03**	70.71 ± 17.50	71.20 ± 17.07	0.00	0.90
impulse_M4	45.86 ± 17.90	45.16 ± 16.25	1.81	0.54	41.82 ± 14.06	49.19 ± 19.24	1.71	0.18
impulse_M5	16.93 ± 8.12	23.39 ± 11.13	1.94	**0.01**	17.58 ± 10.29	20.95 ± 9.12	0.02	0.06
impulse_MF	11.80 ± 4.54	15.65 ± 4.89	0.50	**0.00**	14.56 ± 5.24	11.95 ± 4.47	0.60	**0.03**
impulse_HM	47.53 ± 12.43	47.15 ± 10.73	0.35	0.89	49.38 ± 12.28	45.50 ± 11.07	0.00	0.27
impulse_HL	44.14 ± 11.57	43.85 ± 10.22	0.17	0.96	45.35 ± 11.24	42.78 ± 10.81	0.08	0.55
loading_T1	0.82 ± 0.33	0.62 ± 0.30	0.70	**0.01**	0.85 ± 0.35	0.66 ± 0.29	2.35	**0.01**
loading_T2–5	0.24 ± 0.13	0.25 ± 0.15	0.02	0.89	0.31 ± 0.14	0.19 ± 0.11	2.93	**0.00**
loading_M1	0.83 ± 0.29	0.77 ± 0.26	0.51	0.35	0.86 ± 0.27	0.76 ± 0.29	0.00	0.14
loading_M2	1.32 ± 0.34	1.24 ± 0.32	1.15	0.53	1.41 ± 0.34	1.17 ± 0.28	0.97	**0.00**
loading_M3	1.34 ± 0.30	1.29 ± 0.37	0.41	0.28	1.42 ± 0.35	1.23 ± 0.29	0.58	**0.01**
loading_M4	0.88 ± 0.28	0.90 ± 0.28	0.44	0.82	0.90 ± 0.25	0.88 ± 0.30	0.39	0.47
loading_M5	0.49 ± 0.17	0.55 ± 0.25	2.43	0.55	0.51 ± 0.23	0.52 ± 0.19	0.06	0.51
loading_MF	0.43 ± 0.18	0.54 ± 0.25	3.92	0.13	0.53 ± 0.23	0.41 ± 0.18	0.28	**0.02**
loading_HM	2.46 ± 0.64	2.26 ± 0.69	0.13	0.15	2.56 ± 0.74	2.22 ± 0.55	2.79	**0.02**
loading_HL	2.24 ± 0.68	2.13 ± 0.70	0.58	0.51	2.32 ± 0.71	2.08 ± 0.65	0.09	0.22

Values within the group are means ± SD; Values in bold are statistically significant, i.e., p-values < 0.05.

Table 5
Significance statistics of time-related features in age group and gender group.

Features	Age				Gender			
	Young	Old	F	p	Male	Female	F	p
peak_time_T1	0.78 ± 0.04	0.78 ± 0.15	0.85	**0.03**	0.76 ± 0.13	0.79 ± 0.04	0.43	0.21
peak_time_T2–5	0.75 ± 0.12	0.79 ± 0.03	0.91	**0.00**	0.77 ± 0.03	0.75 ± 0.13	2.50	0.90
peak_time_M1	0.70 ± 0.05	0.69 ± 0.03	1.96	0.06	0.68 ± 0.05	0.71 ± 0.04	0.20	**0.03**
peak_time_M2	0.72 ± 0.03	0.71 ± 0.03	0.43	0.19	0.70 ± 0.03	0.72 ± 0.02	0.09	**0.00**
peak_time_M3	0.70 ± 0.03	0.71 ± 0.03	0.03	0.66	0.69 ± 0.03	0.71 ± 0.03	0.02	**0.00**
peak_time_M4	0.62 ± 0.09	0.65 ± 0.07	1.67	0.26	0.62 ± 0.07	0.64 ± 0.09	0.01	0.10
peak_time_M5	0.54 ± 0.11	0.57 ± 0.09	0.83	0.33	0.55 ± 0.10	0.56 ± 0.10	0.60	0.66
peak_time_MF	0.30 ± 0.06	0.31 ± 0.09	2.16	0.75	0.29 ± 0.05	0.32 ± 0.09	6.95	0.14
peak_time_HM	0.19 ± 0.03	0.20 ± 0.04	0.40	0.14	0.20 ± 0.03	0.18 ± 0.04	0.01	**0.02**
peak_time_HL	0.19 ± 0.03	0.19 ± 0.04	0.04	0.36	0.19 ± 0.04	0.19 ± 0.03	0.03	0.49
contact_time_T1	0.67 ± 0.12	0.63 ± 0.20	7.77	0.65	0.66 ± 0.17	0.64 ± 0.13	0.48	0.37
contact_time_T2–5	0.50 ± 0.14	0.50 ± 0.16	0.04	0.84	0.51 ± 0.13	0.49 ± 0.17	1.15	0.56
contact_time_M1	0.77 ± 0.06	0.76 ± 0.08	0.13	0.65	0.75 ± 0.06	0.77 ± 0.07	0.07	0.06
contact_time_M2	0.83 ± 0.04	0.83 ± 0.05	0.03	1.00	0.81 ± 0.05	0.84 ± 0.03	0.73	**0.01**
contact_time_M3	0.85 ± 0.04	0.86 ± 0.03	0.16	0.71	0.84 ± 0.04	0.87 ± 0.03	0.62	**0.00**
contact_time_M4	0.84 ± 0.04	0.85 ± 0.03	0.27	0.22	0.83 ± 0.04	0.86 ± 0.03	1.53	**0.01**
contact_time_M5	0.76 ± 0.07	0.80 ± 0.05	2.45	**0.03**	0.76 ± 0.07	0.79 ± 0.06	0.45	**0.01**
contact_time_MF	0.68 ± 0.08	0.71 ± 0.06	1.15	0.10	0.68 ± 0.06	0.70 ± 0.09	1.02	0.13
contact_time_HM	0.56 ± 0.06	0.58 ± 0.07	0.55	0.12	0.57 ± 0.06	0.57 ± 0.07	0.43	0.56
contact_time_HL	0.55 ± 0.06	0.57 ± 0.07	0.64	0.12	0.55 ± 0.06	0.56 ± 0.07	1.34	0.65
phase_ICP	0.08 ± 0.03	0.07 ± 0.02	1.78	**0.01**	0.09 ± 0.03	0.07 ± 0.02	2.16	**0.01**
phase_FFCP	0.11 ± 0.06	0.12 ± 0.08	0.05	0.62	0.13 ± 0.07	0.10 ± 0.07	0.08	**0.05**
phase_FFP	0.38 ± 0.08	0.41 ± 0.10	0.69	0.20	0.38 ± 0.08	0.41 ± 0.09	0.21	0.12
phase_FFPOP	0.41 ± 0.06	0.39 ± 0.07	0.43	0.11	0.40 ± 0.06	0.40 ± 0.07	0.58	0.55

than that in female group. The contact time of the male group in the metatarsal region (M2, M3, M4, M5 zones) was significantly higher than that of the female group, while the contact time of the heel region (HM, HL zones) was shorter than that of the female group. Meanwhile, the duration of ICP and FFCP were significantly longer in the male group than in the female group, but the duration of FFP and FFOP were shorter than in the female group. It shows that the main contact part of the male group during walking is the forefoot (metatarsal area), while the female group is biased towards the heel area.

3.1.3. Differences in balance-related features

Table 6 shows the statistical results of the balance-related features. In the comparison between the youth group and the elderly group, no significant difference was found in most features. This suggests that balance-related features are almost independent of age to healthy subjects. The peak and mean of foot balance and forefoot balance were significantly higher in the female group than in the male group. It indicates that the lateral pressure difference of women during walking is large, meaning that the lateral stability may be poor.

Table 6
Significance statistics of balance-related features in age group and gender group.

Features	Age				Gender			
	Young	Old	F	p	Male	Female	F	p
foot balance_peak	173.91 ± 46.30	162.78 ± 44.33	0.88	0.28	156.26 ± 34.63	182.66 ± 51.27	4.86	**0.01**
foot balance_mean	66.58 ± 18.38	64.22 ± 20.67	0.08	0.49	59.45 ± 12.52	71.65 ± 22.45	13.66	**0.04**
foot balance_SD	55.58 ± 16.30	51.71 ± 15.27	1.22	0.25	50.81 ± 11.73	57.33 ± 18.71	6.59	0.25
forefoot balance_peak	171.26 ± 49.02	155.29 ± 43.12	1.48	0.16	152.06 ± 39.02	178.02 ± 51.34	3.49	**0.02**
forefoot balance_mean	62.66 ± 22.11	57.68 ± 19.26	1.06	0.33	54.00 ± 14.41	67.29 ± 24.42	7.66	**0.04**
forefoot balance_SD	55.53 ± 15.64	49.73 ± 14.53	0.85	0.12	50.30 ± 13.30	56.32 ± 16.80	2.27	0.22
heel rotation_peak	63.22 ± 31.04	56.13 ± 23.17	0.06	0.36	54.37 ± 20.57	66.52 ± 33.48	1.15	0.10
heel rotation_mean	16.72 ± 8.33	16.97 ± 7.58	0.07	0.65	15.49 ± 6.45	18.06 ± 9.17	1.17	0.28
heel rotation_SD	21.23 ± 10.71	19.83 ± 8.87	0.02	0.80	18.75 ± 7.46	22.58 ± 11.77	1.31	0.16
medial forefoot balance_peak	89.97 ± 31.91	84.12 ± 27.79	1.00	0.35	81.29 ± 24.96	94.01 ± 33.96	2.37	0.14
medial forefoot balance_mean	31.85 ± 12.34	27.51 ± 8.44	1.83	0.11	28.59 ± 9.34	31.83 ± 12.62	1.23	0.48
medial forefoot balance_SD	29.56 ± 10.64	27.26 ± 9.46	0.47	0.38	27.03 ± 8.82	30.31 ± 11.27	2.16	0.17
metatarsal loading peak	147.94 ± 54.66	128.84 ± 41.79	4.56	0.12	126.54 ± 38.53	154.53 ± 57.50	6.35	**0.02**
metatarsal loading mean	45.73 ± 19.32	38.81 ± 12.14	5.43	0.19	39.41 ± 13.83	46.77 ± 19.47	4.13	0.15
metatarsal_loading_SD	45.33 ± 17.96	38.41 ± 13.19	5.22	0.12	40.35 ± 14.43	45.10 ± 18.31	2.98	0.38

Table 7
Significance statistics of static features (eyes open) in age group and gender group.

Features	Age				Gender			
	Young	Old	F	p	Male	Female	F	p
x range	8.50 ± 4.62	9.29 ± 3.54	0.51	0.21	8.08 ± 3.53	9.46 ± 4.78	1.25	0.28
y range	12.67 ± 7.16	13.30 ± 7.05	0.08	0.45	10.36 ± 4.23	15.32 ± 8.37	10.03	**0.01**
ellipse area	95.99 ± 104.66	109.10 ± 94.49	0.06	0.14	71.11 ± 63.80	129.00 ± 120.32	6.87	0.06
x velocity_RMS	6.76 ± 1.64	7.14 ± 2.01	0.03	0.40	6.22 ± 1.05	7.55 ± 2.09	5.44	**0.00**
y velocity_RMS	6.58 ± 1.74	6.76 ± 1.25	2.01	0.29	6.36 ± 1.22	6.92 ± 1.82	3.81	0.24
COP speed_RMS	9.47 ± 2.23	9.88 ± 2.15	0.31	0.24	8.92 ± 1.46	10.29 ± 2.56	6.90	**0.02**
x acceleration_RMS	0.44 ± 0.12	0.47 ± 0.17	0.39	0.39	0.40 ± 0.08	0.50 ± 0.16	4.38	**0.00**
y acceleration_RMS	0.37 ± 0.07	0.35 ± 0.06	1.25	0.25	0.36 ± 0.06	0.36 ± 0.07	0.32	0.63
COP_acceleration_RMS	0.33 ± 0.07	0.34 ± 0.08	0.11	0.57	0.31 ± 0.05	0.35 ± 0.08	4.09	**0.05**
x_SampEn	0.28 ± 0.15	0.26 ± 0.18	0.01	0.59	0.27 ± 0.17	0.27 ± 0.16	0.02	0.97
y_SampEn	0.15 ± 0.09	0.14 ± 0.07	0.90	0.95	0.17 ± 0.08	0.13 ± 0.08	0.08	**0.00**
x velocity_SampEn	2.06 ± 0.09	2.07 ± 0.07	0.65	0.95	2.06 ± 0.07	2.07 ± 0.09	0.05	0.40
y velocity_SampEn	1.94 ± 0.13	1.90 ± 0.13	0.18	0.14	1.94 ± 0.13	1.91 ± 0.13	0.00	0.17
COP speed_SampEn	1.92 ± 0.12	1.91 ± 0.09	0.29	0.27	1.94 ± 0.09	1.90 ± 0.12	0.97	0.15
sway density_peak	80.08 ± 39.91	66.86 ± 20.14	3.56	0.36	76.19 ± 29.99	74.28 ± 38.42	0.18	0.50
sway density_SD	15.77 ± 8.09	13.00 ± 4.38	2.17	0.36	14.99 ± 5.86	14.52 ± 8.07	0.03	0.31
sway density_mean	21.50 ± 9.54	17.81 ± 5.53	4.42	0.15	21.19 ± 7.22	19.15 ± 9.42	0.59	0.09
sway length_peak	9.34 ± 4.03	8.22 ± 2.74	2.10	0.33	8.86 ± 3.50	8.99 ± 3.79	0.82	0.93
sway length_mean	2.62 ± 0.99	2.27 ± 0.63	2.88	0.21	2.55 ± 0.79	2.44 ± 0.97	0.01	0.24
sway length_SD	1.72 ± 0.83	1.48 ± 0.51	2.21	0.36	1.63 ± 0.68	1.64 ± 0.79	0.44	0.69
sway radius_peak	1.28 ± 0.50	1.23 ± 0.33	2.12	0.95	1.16 ± 0.34	1.37 ± 0.50	2.54	0.07
sway radius_mean	0.32 ± 0.08	0.34 ± 0.07	0.55	0.15	0.31 ± 0.06	0.35 ± 0.09	5.16	**0.03**
sway radius_SD	0.17 ± 0.06	0.18 ± 0.04	1.14	0.17	0.16 ± 0.04	0.19 ± 0.06	4.19	**0.04**

3.1.4. Differences in static features with eyes open

Table 7 shows the statistical results of static features in the eye opened state. There are no significant differences in all static features between the young and old groups in the open eye state. Compared with the female group, the sample entropy of coordinate of COP in the male group is significantly higher than that in the female group indicating that the COP of males changed more frequently in the lateral direction. The RMS of the x velocity of COP and the COP speed is significantly higher in the female group than in the male group. At the same time, the sway density related features (including peak, mean, SD) of the female group are significantly higher than those of the male group. Therefore, in the state of open eyes, the static balance ability of females may be worse than that of males. On the whole, in the state of open eyes, there is no obvious and consistent difference whether it is a group of different ages or a group of different genders.

3.1.5. Differences in static features with eyes closed

Table 8 shows the statistical results of static features in the eyes closed state. In the closed eye state, the y coordinate range of COP in the young group is significantly lower than that in the old group, while the sample entropy of COP displacement is significantly higher than that of the old group. The RMS of COP velocity and acceleration of COP in each direction of the young group is significantly lower than those of the old group, indicating that the COP movement is more intense in the old group. In terms of sway-related features, the related features (including peak, mean, SD) of sway density and sway length in the young group are significantly higher than those in the old group, while the related features (including peak, mean, SD) of sway radius are significantly lower than those in the old group. This all shows the same conclusion: in the state of eyes closed, the body shaking of the old group is more obvious than that of the young group, and the static stability is worse. However, the difference in static features between the male group and the female group in the closed eye state is not obvious, and only significant difference is found in the x acceleration of COP.

3.2. Multi-factor regression results

In this part, we consider the effects of age, gender, height, weight, shoe size, and BMI to perform regression analysis. Each factor is tested by taking as independent variable to perform the analysis using the ridge regression method. The analysis results of various features are given below. The results include the relevant indicators of the regression model: the adjusted r^2, indicating the degree of fitting performance; and the p value, representing whether the overall regression model is statistically significant ($p < 0.05$) or not. The standardized coefficient β and p value of each factor, reflecting the factor influence on the feature, are also obtained.

Table 8
Difference statistics of static features (eyes closed) in age group and gender group.

Features	Age				Gender			
	Young	Old	F	p	Male	Female	F	p
x range	9.12 ± 4.53	10.63 ± 6.52	0.68	0.31	9.97 ± 6.52	9.40 ± 4.04	0.94	0.63
y range	12.93 ± 8.45	18.02 ± 10.28	1.29	**0.01**	12.78 ± 5.61	16.72 ± 11.75	5.17	0.47
ellipse area	111.91 ± 123.16	168.51 ± 176.16	1.56	0.08	111.60 ± 104.85	152.85 ± 176.47	1.78	0.49
x velocity_RMS	7.17 ± 1.60	8.23 ± 2.01	0.20	**0.01**	7.30 ± 1.67	7.81 ± 1.96	1.81	0.17
y velocity_RMS	7.11 ± 1.93	8.92 ± 2.40	0.61	**0.00**	7.45 ± 1.84	8.09 ± 2.60	3.51	0.29
COP speed_RMS	10.13 ± 2.34	12.22 ± 2.77	0.07	**0.00**	10.46 ± 2.33	11.32 ± 2.95	2.84	0.19
x acceleration_RMS	0.45 ± 0.11	0.50 ± 0.15	1.54	0.19	0.44 ± 0.10	0.50 ± 0.14	3.04	**0.03**
y acceleration_RMS	0.39 ± 0.07	0.38 ± 0.06	3.30	0.85	0.39 ± 0.06	0.38 ± 0.07	0.95	0.70
COP_acceleration_RMS	0.35 ± 0.07	0.38 ± 0.07	0.00	**0.03**	0.35 ± 0.06	0.37 ± 0.08	4.47	0.23
x_SampEn	0.26 ± 0.17	0.27 ± 0.16	0.07	0.83	0.24 ± 0.14	0.28 ± 0.19	0.84	0.76
y_SampEn	0.16 ± 0.08	0.15 ± 0.07	0.81	0.43	0.16 ± 0.07	0.16 ± 0.09	2.26	0.83
x velocity_SampEn	2.06 ± 0.12	2.00 ± 0.14	2.34	**0.03**	2.01 ± 0.15	2.06 ± 0.10	4.05	0.20
y velocity_SampEn	1.95 ± 0.14	1.76 ± 0.17	1.54	**0.00**	1.91 ± 0.17	1.85 ± 0.18	0.01	0.15
COP speed_SampEn	1.93 ± 0.10	1.79 ± 0.14	4.99	**0.00**	1.89 ± 0.14	1.88 ± 0.14	0.15	0.65
sway density_peak	69.25 ± 43.11	49.29 ± 16.42	3.87	**0.03**	59.38 ± 20.83	64.28 ± 47.31	2.33	0.45
sway density_SD	13.45 ± 9.00	9.57 ± 3.22	3.48	**0.05**	11.86 ± 4.55	12.18 ± 9.71	1.13	0.12
sway density_mean	18.26 ± 9.70	12.57 ± 4.69	5.74	**0.01**	16.42 ± 7.10	15.92 ± 9.92	0.65	0.18
sway length_peak	8.51 ± 5.38	6.32 ± 2.46	1.20	**0.02**	7.14 ± 2.73	8.24 ± 5.87	1.32	0.75
sway length_mean	2.34 ± 1.03	1.74 ± 0.56	3.02	**0.00**	2.12 ± 0.77	2.11 ± 1.06	0.07	0.53
sway length_SD	1.56 ± 1.08	1.12 ± 0.45	1.53	**0.02**	1.34 ± 0.56	1.45 ± 1.17	0.44	0.72
sway radius_peak	1.28 ± 0.45	1.71 ± 0.47	0.06	**0.00**	1.35 ± 0.45	1.52 ± 0.54	1.51	0.16
sway radius_mean	0.35 ± 0.09	0.43 ± 0.10	0.09	**0.00**	0.36 ± 0.09	0.39 ± 0.11	2.77	0.17
sway radius_SD	0.19 ± 0.07	0.25 ± 0.08	0.11	**0.00**	0.20 ± 0.07	0.22 ± 0.09	1.07	0.31

3.2.1. Influence on pressure-related features

Table 9 presents the regression results of the pressure-related features. It can be seen that the regression results for most of the features are statistically significant ($p < 0.05$). Since there is clearly a high correlation between pressure and weight, it is obvious that weight is the most influential factor for most pressure-related features. BMI and weight are similar, with high correlations to the pressure-related features. In addition, it can be observed that the features significantly affected by age are: the pressure peaks in the T1, M2, M3, HM and HL zones, the impulses in the M3, M5 and MF zones, the loading in the T1, M2, M3, HM and HL zones. It can be explained that these pressure-related features will change with age. Among the standardized coefficients of gender, those with significant effects include: the peak pressures in the T1, T2-5, M4, and M5 zones, the impulses in the T1, T2-5, M4, and M5 zones, and the loading in the T1 and T2-5 zones. It means these pressure-related features have significant differences between male and female. Height and shoe size show little significant effects on pressure-related features. The peak pressure in the M2 and HL zones, the impulse in the M1 and M2 zones, and the loading in the MF zone are significantly affected by height. The peak pressure in the MF zone, the impulse in the MF zone and the loading in the Hl zone are significantly affected by the shoe size. In general, there are certain differences in the distribution of plantar pressure among groups of different ages and genders.

3.2.2. Influence on time-related features

Table 10 shows the regression results of time-related features. In terms of time-related features, there are few regression models with statistical significance ($p < 0.05$). The features of regression models with statistical significance include: the peak time in the M2 and M3 zones, the contact time in the M3, M4, M5, and MF zones and the duration of ICP. Among them, besides that the duration of ICP is significantly affected by age, no other features that were significantly affected by age were found. Features significantly affected by gender were: the peak time in the M2 zones, the contact time in the M2, M3, M4, M5 zones, and the duration of ICP. Height had a significant effect on the features of the peak time in the M2 zone, the contact time in the M1 zone, the duration of FFCP and FFP. Body weight had a significant effect on the peak time in the M2 and M3 zones, the contact time in the T2-5, M3, M4, M5, and MF zones, and the duration of ICP. Shoe size had a significant effect on the peak time in the T1 zones, the contact time in the M1, M4 and M5 zones, and the duration of FFP. BMI had a significant effect on the peak time in the T1 zone, the contact time in the T1 and MF zones, and the duration of ICP and FFP. In general, the time-related features are generally less affected by above factors, among which gender and age are two influential factors with relatively large degree of influence.

3.2.3. Influence on balance-related features

Table 11 shows the regression analysis results for the balance-related features. All regression results for these features were statistically significant ($p < 0.05$). It can be clearly seen that body weight was the most important factor affecting such features, and the standardization coefficient of body weight were all positive. This means that the greater the weight is, the greater the difference in the horizontal pressure of the human body is, which means that the stability of the walking process is poor. The effect of age on these features was not found to be significant. Features that were significantly affected by gender were the mean and SD of medial forefoot balance, and the peak and SD of metatarsal loading, all of which were negatively correlated with gender. Features significantly affected by height were: the peak and SD of foot balance, the peak and SD of forefoot balance, and the mean and SD of metatarsal loading. Features significantly affected by shoe size were: the peak and SD of heel rotation, the peak, mean, SD of medial forefoot balance and metatarsal loading. Features significantly affected by BMI were: the peak and SD of foot balance, the peak of forefoot balance, and the mean of heel rotation. It can be seen that the value of the balance-related features is most sensitive to body weight, and gender and shoe size have a significant impact on the balance-related features in the metatarsal region.

3.2.4. Influence on static features with eyes open

Table 12 shows the regression analysis results of the static features in the open eye state. The features of regression results with statistical significance ($p < 0.05$) include: RMS of x velocity of COP, COP velocity, x acceleration of COP, y acceleration of COP and COP acceleration; sample entropy of y coordinate, and the mean of sway density. The features significantly affected by age are: the RMS of x velocity of COP, COP speed, x acceleration of COP and COP acceleration, the peak, mean and SD of sway density, the mean of sway density. Among them, the velocity of COP related features and the mean of sway density were positively correlated with age, and the related features of sway

Table 9
Regression results of pressure-related features.

Features	Adjusted r^2	p	Age		Gender		Height		Weight		Shoe size		BMI	
			β	p	β	p	β	p	β	p	β	p	β	p
peak pressure_T1	0.08	0.07	−0.21	**0.05**	−0.34	**0.02**	−0.16	0.15	0.01	0.46	0.34	**0.05**	−0.20	**0.04**
peak pressure_T2–5	−0.02	0.57	0.02	0.45	−0.33	**0.03**	0.14	0.20	−0.06	0.31	0.06	0.39	0.09	0.22
peak pressure_M1	−0.04	0.75	−0.10	0.24	0.02	0.46	0.17	0.15	0.00	0.49	−0.15	0.24	0.22	**0.03**
peak pressure_M2	0.33	**0.00**	−0.20	**0.01**	−0.07	0.21	0.13	**0.05**	0.32	**0.00**	−0.14	0.06	0.30	**0.00**
peak pressure_M3	0.27	**0.00**	−0.22	**0.01**	0.05	0.31	−0.03	0.37	0.28	**0.00**	0.01	0.48	0.27	**0.00**
peak pressure_M4	0.21	**0.00**	−0.06	0.25	0.24	**0.01**	0.00	0.48	0.20	**0.00**	−0.03	0.38	0.20	**0.00**
peak pressure_M5	0.14	**0.01**	0.19	0.06	0.28	**0.04**	−0.13	0.20	0.19	**0.05**	0.00	0.50	0.07	0.25
peak pressure_MF	0.27	**0.00**	0.06	0.25	0.00	0.48	−0.10	0.13	0.20	**0.00**	−0.24	**0.00**	0.29	**0.00**
peak pressure_HM	0.25	**0.00**	−0.26	**0.00**	−0.04	0.35	0.05	0.32	0.29	**0.00**	−0.02	0.43	0.23	**0.00**
peak pressure_HL	0.28	**0.00**	−0.20	**0.01**	0.01	0.47	0.14	**0.05**	0.29	**0.00**	−0.11	0.11	0.25	**0.00**
impulse_T1	0.05	0.16	−0.14	0.13	−0.33	**0.03**	−0.05	0.38	0.08	0.25	0.23	0.13	−0.24	**0.02**
impulse_T2–5	−0.02	0.59	0.05	0.34	−0.30	**0.04**	0.23	0.09	−0.01	0.47	−0.04	0.43	0.05	0.33
impulse_M1	−0.01	0.52	−0.07	0.27	0.07	0.32	0.22	**0.05**	0.12	0.10	−0.25	0.06	0.10	0.13
impulse_M2	0.19	**0.00**	−0.12	0.08	−0.04	0.34	0.22	**0.00**	0.26	**0.00**	−0.11	0.09	0.16	**0.01**
impulse_M3	0.20	**0.00**	−0.17	**0.04**	0.08	0.20	0.10	0.13	0.22	**0.00**	0.02	0.43	0.15	**0.02**
impulse_M4	0.21	**0.00**	−0.04	0.36	0.30	**0.03**	0.06	0.34	0.31	**0.00**	−0.18	0.17	0.15	0.08
impulse_M5	0.22	**0.00**	0.21	**0.04**	0.35	**0.01**	−0.11	0.22	0.24	**0.02**	−0.07	0.36	0.08	0.22
impulse_MF	0.35	**0.00**	0.13	**0.05**	0.05	0.29	−0.07	0.17	0.24	**0.00**	−0.17	**0.03**	0.32	**0.00**
impulse_HM	0.23	**0.00**	−0.02	0.43	0.02	0.42	0.08	0.19	0.27	**0.00**	−0.06	0.26	0.24	**0.00**
impulse_HL	0.21	**0.00**	0.00	0.50	0.05	0.31	0.10	0.14	0.26	**0.00**	−0.06	0.26	0.22	**0.00**
loading_T1	0.07	0.08	−0.26	**0.02**	−0.28	**0.05**	−0.14	0.20	0.07	0.30	0.28	0.09	−0.18	0.06
loading_T2–5	0.04	0.20	−0.04	0.33	−0.18	**0.05**	−0.07	0.23	0.01	0.45	−0.08	0.21	0.07	0.16
loading_M1	−0.02	0.58	−0.14	0.14	0.02	0.45	0.02	0.45	0.03	0.40	−0.01	0.49	0.22	**0.03**
loading_M2	0.21	**0.00**	−0.21	**0.01**	−0.04	0.36	−0.04	0.32	0.24	**0.00**	−0.14	0.08	0.29	**0.00**
loading_M3	0.16	**0.00**	−0.23	**0.03**	0.06	0.35	−0.21	0.08	0.29	**0.01**	−0.01	0.48	0.24	**0.01**
loading_M4	0.09	**0.05**	−0.09	0.23	0.21	0.10	−0.12	0.22	0.20	**0.05**	−0.03	0.45	0.18	0.06
loading_M5	0.07	0.10	0.05	0.35	0.21	0.11	−0.17	0.14	0.22	**0.04**	0.06	0.38	0.03	0.38
loading_MF	0.12	**0.02**	0.05	0.27	0.04	0.29	−0.16	**0.01**	0.07	0.07	−0.10	0.07	0.20	**0.00**
loading_HM	0.19	**0.00**	−0.22	**0.01**	−0.03	0.38	−0.01	0.47	0.23	**0.00**	−0.08	0.19	0.28	**0.00**
loading_HL	0.22	**0.00**	−0.22	**0.03**	0.09	0.29	0.16	0.14	0.14	0.11	−0.30	**0.05**	0.47	**0.00**

β is the standardization coefficient of the regression model.

Table 10
Regression analysis results of time-related features.

Features	Adjusted r^2	p	Age		Gender		Height		Weight		Shoe size		BMI	
			β	p	β	p	β	p	β	p	β	p	β	p
peak_time_T1	0.03	0.26	0.13	0.14	−0.14	0.16	0.11	0.20	0.01	0.47	0.29	**0.03**	−0.15	**0.05**
peak_time_T2–5	−0.02	0.59	0.18	0.08	−0.10	0.28	−0.09	0.30	0.13	0.16	0.03	0.44	−0.05	0.32
peak_time_M1	0.04	0.19	−0.14	0.14	0.05	0.39	0.10	0.26	0.02	0.42	0.10	0.32	0.13	0.13
peak_time_M2	0.14	**0.01**	−0.07	0.19	0.13	**0.04**	0.12	**0.03**	0.12	**0.01**	0.06	0.17	0.05	0.19
peak_time_M3	0.14	**0.01**	0.01	0.46	0.19	0.11	−0.10	0.25	0.28	**0.01**	0.08	0.33	0.04	0.37
peak_time_M4	−0.01	0.49	0.11	0.17	−0.03	0.42	−0.05	0.36	0.08	0.19	0.17	0.14	0.06	0.25
peak_time_M5	−0.05	0.89	0.08	0.28	0.14	0.21	−0.03	0.43	−0.04	0.37	−0.08	0.36	0.11	0.18
peak_time_MF	−0.01	0.51	0.16	0.11	0.14	0.22	0.07	0.33	0.08	0.27	0.02	0.47	−0.08	0.26
peak_time_HM	0.03	0.22	0.08	0.26	−0.24	0.08	0.13	0.22	0.07	0.30	−0.13	0.27	0.14	0.11
peak_time_HL	−0.05	0.90	0.04	0.34	−0.01	0.47	0.01	0.46	0.05	0.24	−0.12	0.15	0.06	0.20
contact_time_T1	0.00	0.42	−0.02	0.43	−0.21	0.11	−0.12	0.22	0.08	0.27	0.27	0.10	−0.31	**0.00**
contact_time_T2–5	−0.04	0.76	−0.03	0.37	−0.10	0.08	0.07	0.13	0.10	**0.03**	−0.02	0.36	0.05	0.18
contact_time_M1	0.00	0.43	−0.05	0.35	0.18	0.15	0.33	**0.02**	0.02	0.43	−0.35	**0.05**	0.11	0.16
contact_time_M2	0.05	0.16	−0.01	0.45	0.23	**0.03**	0.08	0.23	0.07	0.17	−0.03	0.39	0.05	0.26
contact_time_M3	0.16	**0.01**	0.02	0.43	0.44	**0.00**	0.02	0.46	0.25	**0.02**	−0.24	0.11	0.07	0.27
contact_time_M4	0.22	**0.00**	0.06	0.30	0.47	**0.00**	−0.03	0.42	0.37	**0.00**	−0.41	**0.01**	0.10	0.17
contact_time_M5	0.26	**0.00**	0.17	0.07	0.34	**0.01**	0.01	0.48	0.36	**0.00**	−0.29	**0.05**	0.13	0.10
contact_time_MF	0.10	**0.04**	0.07	0.19	0.06	0.21	−0.06	0.18	0.13	**0.01**	0.01	0.45	0.19	**0.00**
contact_time_HM	0.02	0.31	0.07	0.29	−0.03	0.43	0.04	0.41	0.12	0.17	−0.03	0.45	0.18	0.06
contact_time_HL	0.01	0.38	0.10	0.22	0.00	0.49	0.03	0.44	0.11	0.20	−0.01	0.47	0.15	0.10
phase_ICP	0.22	**0.00**	−0.17	**0.03**	−0.35	**0.00**	0.10	0.12	−0.11	**0.04**	0.10	0.14	−0.17	**0.00**
phase_FFCP	−0.01	0.49	0.02	0.45	−0.14	0.21	−0.31	**0.03**	−0.04	0.38	0.28	0.10	−0.11	0.18
phase_FFP	0.11	**0.03**	0.11	0.19	0.18	0.14	0.29	**0.03**	0.14	0.11	−0.32	**0.05**	0.24	**0.02**
phase_FFPOP	0.01	0.34	−0.09	0.25	0.04	0.40	−0.07	0.34	−0.13	0.15	0.02	0.47	−0.16	0.09

length were negatively correlated with age, which reflected that the balance of the old group with eyes open was worse than that of the young group. Features significantly affected by gender were: y range, the RMS of x velocity of COP, COP speed, x acceleration of COP, COP acceleration and the sample entropy of y coordinate of COP, mean and SD of sway density. The coefficients of these features and gender were mostly positive, because gender was used as a dummy variable: male is set to 0 and female to 1, which reflects that the value of females on these features was higher than that of males, which means poor balance stability. No features were found to be significantly affected by height and shoe size. Weight had a significant effect on the RMS of velocity and acceleration of COP, the sample entropy of y coordinate of COP and the mean of sway density. BMI had a significant effect on the RMS of acceleration of COP, the sample entropy of y coordinate of COP, y velocity of COP, and COP speed. Overall, no one factor had a particularly prominent effect in the eyes open state, and age, gender, weight, and BMI all had an impact on static features to a certain extent.

Table 11
Regression analysis results of balance-related features.

Features	Adjusted r^2	p	Age		Gender		Height		Weight		Shoe size		BMI	
			β	p	β	p	β	p	β	p	β	p	β	p
foot_balance_peak	0.30	**0.00**	−0.10	0.13	−0.04	0.31	0.18	**0.02**	0.26	**0.00**	0.09	0.16	0.19	**0.00**
foot_balance_mean	0.34	**0.00**	−0.04	0.34	−0.09	0.26	0.16	0.11	0.37	**0.00**	0.13	0.22	0.13	0.09
foot_balance_SD	0.20	**0.00**	−0.09	0.21	−0.13	0.21	0.28	**0.03**	0.26	**0.01**	−0.01	0.49	0.17	**0.05**
forefoot_balance_peak	0.30	**0.00**	−0.14	0.10	−0.14	0.16	0.25	**0.03**	0.21	**0.02**	0.14	0.21	0.24	**0.01**
forefoot_balance_mean	0.23	**0.00**	−0.09	0.21	−0.07	0.33	0.10	0.23	0.22	**0.03**	0.23	0.11	0.15	0.07
forefoot_balance_SD	0.20	**0.00**	−0.11	0.16	−0.22	0.08	0.32	**0.02**	0.17	0.07	0.11	0.28	0.17	0.06
heel_rotation_peak	0.18	**0.00**	−0.17	0.07	−0.11	0.24	−0.17	0.12	0.24	**0.02**	0.38	**0.02**	0.11	0.14
heel_rotation_mean	0.21	**0.00**	−0.11	0.16	−0.04	0.40	−0.13	0.18	0.25	**0.01**	0.19	0.16	0.24	**0.01**
heel_rotation_SD	0.16	**0.01**	−0.14	0.13	−0.09	0.28	−0.16	0.14	0.22	**0.03**	0.33	**0.04**	0.14	0.09
medial_forefoot_balance_peak	0.22	**0.00**	−0.06	0.30	−0.24	0.06	0.08	0.30	0.31	**0.00**	0.30	**0.05**	0.06	0.28
medial_forefoot_balance_mean	0.19	**0.00**	−0.07	0.26	−0.37	**0.01**	0.19	0.10	0.23	**0.02**	0.34	**0.04**	−0.02	0.43
medial_forefoot_balance_SD	0.23	**0.00**	−0.03	0.38	−0.37	**0.01**	0.11	0.21	0.32	**0.00**	0.37	**0.02**	0.00	0.49
metatarsal_loading_peak	0.28	**0.00**	−0.11	0.17	−0.24	**0.05**	0.05	0.35	0.34	**0.00**	0.37	**0.02**	−0.03	0.39
metatarsal_loading_mean	0.17	**0.00**	−0.08	0.17	−0.13	0.07	0.14	**0.03**	0.15	**0.00**	0.24	**0.00**	0.01	0.44
metatarsal_loading_SD	0.18	**0.00**	−0.12	0.08	−0.17	**0.02**	0.13	**0.03**	0.19	**0.00**	0.20	**0.01**	0.06	0.16

Table 12
Regression analysis results of static features (eyes open).

Features	Adjusted r^2	p	Age		Gender		Height		Weight		Shoe size		BMI	
			β	p	β	p	β	p	β	p	β	p	β	p
x range	−0.03	0.70	0.09	0.25	0.18	0.16	0.14	0.20	−0.02	0.44	−0.13	0.27	0.13	0.13
y range	0.05	0.14	0.09	0.23	0.31	**0.03**	0.05	0.39	−0.04	0.37	0.03	0.45	0.04	0.37
ellipse area	0.02	0.29	0.10	0.21	0.24	0.08	0.15	0.18	−0.10	0.22	−0.02	0.47	0.13	0.13
x velocity_RMS	0.17	**0.00**	0.14	**0.05**	0.39	**0.00**	−0.08	0.17	−0.15	**0.01**	0.03	0.34	−0.10	0.06
y velocity_RMS	0.03	0.23	0.20	0.06	0.11	0.25	0.13	0.21	−0.21	**0.05**	0.11	0.30	−0.11	0.18
COP speed_RMS	0.13	**0.01**	0.18	**0.05**	0.37	**0.00**	−0.03	0.39	−0.19	**0.01**	0.05	0.37	−0.12	0.07
x acceleration_RMS	0.18	**0.00**	0.15	**0.03**	0.32	**0.00**	−0.06	0.16	−0.14	**0.00**	0.06	0.17	−0.12	**0.01**
y acceleration_RMS	0.31	**0.00**	0.09	0.15	0.01	0.44	0.10	0.10	−0.26	**0.00**	0.05	0.29	−0.35	**0.00**
COP_acceleration_RMS	0.24	**0.00**	0.18	**0.03**	0.35	**0.00**	−0.05	0.30	−0.23	**0.00**	0.02	0.43	−0.22	**0.00**
x_SampEn	−0.02	0.59	−0.02	0.44	0.16	0.18	−0.11	0.26	−0.05	0.35	−0.08	0.34	−0.16	0.08
y_SampEn	0.10	**0.04**	0.03	0.38	−0.19	**0.04**	0.08	0.19	−0.13	**0.03**	−0.04	0.36	−0.18	**0.01**
x velocity_SampEn	−0.06	0.94	0.12	0.19	0.02	0.45	−0.05	0.37	0.03	0.42	0.09	0.34	−0.17	0.08
y velocity_SampEn	0.00	0.47	−0.08	0.25	−0.13	0.19	0.04	0.38	−0.02	0.43	−0.02	0.44	−0.16	**0.04**
COP speed_SampEn	0.01	0.36	−0.01	0.48	−0.17	0.17	−0.01	0.47	0.06	0.32	−0.06	0.39	−0.24	**0.02**
sway density_peak	0.00	0.42	−0.29	**0.01**	0.01	0.48	−0.17	0.15	0.16	0.11	−0.03	0.44	0.07	0.29
sway density_SD	0.03	0.25	−0.28	**0.01**	−0.15	0.14	−0.10	0.23	0.11	0.11	0.03	0.42	0.08	0.19
sway density_mean	−0.01	0.50	−0.23	**0.03**	−0.08	0.28	−0.07	0.29	0.14	0.07	0.02	0.46	0.05	0.28
sway length_peak	−0.05	0.88	−0.17	0.11	0.07	0.34	−0.17	0.15	0.08	0.27	0.01	0.48	−0.10	0.19
sway length_mean	−0.03	0.72	−0.20	0.06	−0.10	0.28	−0.15	0.18	0.08	0.27	0.11	0.30	−0.09	0.23
sway length_SD	−0.05	0.87	−0.16	0.12	−0.03	0.44	−0.16	0.17	0.13	0.17	0.09	0.34	−0.14	0.12
sway radius_peak	−0.01	0.54	0.01	0.47	0.13	0.10	−0.01	0.48	−0.07	0.15	0.14	0.07	−0.03	0.33
sway radius_mean	0.10	**0.04**	0.18	**0.05**	0.35	**0.01**	0.00	0.49	−0.17	**0.03**	0.02	0.46	−0.10	0.12
sway radius_SD	0.02	0.30	0.12	0.16	0.24	**0.05**	0.01	0.46	−0.12	0.10	0.09	0.29	−0.02	0.42

3.2.5. Influence on static features with eyes closed

Table 13 shows the regression analysis results of the static features in the eyes closed state. Among them, the regression results with statistical significance ($p < 0.05$) include: y coordinate range of COP, RMS of velocity and acceleration of COP, sample entropy of y velocity of COP and COP speed, the peak, the mean and the SD of sway density. It can be seen that age was the most obvious influencing factor, and all features showed significant correlation with age, except for x coordinate range of COP, the sample entropy of COP coordinate. According to the results, a consistent conclusion can be drawn: the elderly is less stable than youth with their eyes closed. Such features were less affected by gender significance and included: RMS of x velocity of COP, x acceleration of COP and COP acceleration, the sample entropy of x coordinate of COP. Affected by the significance of weight were: RMS of x velocity of COP, x acceleration of COP, y acceleration of COP and COP acceleration, the sample entropy of x coordinate of COP, y coordinate of COP, x velocity of COP, y velocity of COP and COP speed. Significantly affected by weight were: RMS of x velocity of COP, x acceleration of COP, y acceleration of COP and COP acceleration, the sample entropy of x coordinate of COP, y coordinate of COP, x velocity of COP, y velocity of COP and COP speed. The only feature that was significantly affected by shoe size was the sample entropy of x velocity of COP. The features that were significantly affected by BMI were: RMS of x velocity of COP, COP speed, and acceleration of COP in each direction and the sample entropy of y velocity. Overall, age was the most important factor in the eyes closed state, and it had a significant impact on almost all features. In addition, gender, weight, and BMI also had a significant effect on many features, while height and shoe size had little effect.

3.3. Comparison of the two methods

This part is aimed at the above two analysis methods, including: statistical test method, regression analysis method, starting from the results to compare and verify each other, so as to obtain more reliable conclusions. The discussion here will only focus on the effects of age and gender on features.

3.3.1. Age effect

Among the pressure-related features, statistical test method and regression analysis method yielded roughly the same results. However, there were relatively more features showing a significant effect in the regression analysis, which may be because the pressure-related features are greatly affected by body weight and BMI. It is difficult to exclude the influence of these two factors in the group comparison. Neither method found many statistically significant results in the time-related features, but comparing the p-values of the two methods, the

Table 13
Regression analysis results of static features (eyes closed).

Features	Adjusted r^2	p	Age		Gender		Height		Weight		Shoe size		BMI	
			β	p	β	p	β	p	β	p	β	p	β	p
x_range	−0.03	0.68	0.12	0.12	−0.04	0.36	0.14	0.08	0.11	0.06	−0.17	0.06	−0.01	0.44
y_range	0.10	**0.04**	0.33	**0.00**	0.08	0.28	0.25	**0.02**	0.10	0.12	−0.08	0.29	−0.01	0.44
ellipse_area	0.06	0.11	0.28	**0.01**	0.00	0.49	0.34	**0.02**	0.19	0.06	−0.19	0.17	−0.05	0.32
x_velocity_RMS	0.10	**0.03**	0.26	**0.00**	0.16	**0.02**	0.03	0.34	−0.09	**0.04**	−0.04	0.29	−0.13	**0.01**
y_velocity_RMS	0.16	**0.00**	0.51	**0.00**	−0.01	0.48	0.25	**0.05**	0.08	0.25	0.00	0.50	−0.12	0.14
COP_speed_RMS	0.17	**0.00**	0.50	**0.00**	0.14	0.18	0.19	0.10	0.02	0.43	−0.08	0.33	−0.18	**0.05**
x_acceleration_RMS	0.18	**0.00**	0.25	**0.00**	0.30	**0.00**	−0.04	0.32	−0.18	**0.00**	0.07	0.24	−0.18	**0.00**
y_acceleration_RMS	0.25	**0.00**	0.17	**0.03**	−0.06	0.27	0.15	**0.04**	−0.20	**0.00**	0.04	0.32	−0.35	**0.00**
COP_acceleration_RMS	0.20	**0.00**	0.34	**0.00**	0.19	**0.03**	0.06	0.25	−0.16	**0.01**	−0.01	0.46	−0.24	**0.00**
x_SampEn	0.03	0.23	0.02	0.45	0.27	**0.05**	−0.28	**0.04**	−0.21	**0.05**	0.13	0.26	−0.07	0.27
y_SampEn	−0.01	0.55	−0.05	0.31	0.04	0.35	−0.12	0.11	−0.14	**0.02**	0.12	0.14	−0.09	0.12
x_velocity_SampEn	0.05	0.15	−0.21	**0.05**	0.14	0.20	−0.19	0.11	−0.22	**0.04**	0.33	**0.05**	0.05	0.32
y_velocity_SampEn	0.35	**0.00**	−0.43	**0.00**	−0.09	0.20	−0.08	0.20	−0.14	**0.01**	0.03	0.39	−0.15	**0.01**
COP_speed_SampEn	0.28	**0.00**	−0.49	**0.00**	0.03	0.41	−0.21	0.07	−0.23	**0.02**	0.14	0.21	−0.05	0.31
sway_density_peak	0.02	0.27	−0.33	**0.01**	0.21	0.11	−0.18	0.13	−0.05	0.34	−0.05	0.41	0.07	0.27
sway_density_mean	0.08	0.06	−0.44	**0.00**	0.06	0.36	−0.26	**0.05**	0.04	0.38	0.02	0.46	0.11	0.17
sway_density_SD	0.02	0.30	−0.35	**0.00**	0.16	0.17	−0.21	0.10	−0.01	0.47	−0.05	0.40	0.09	0.22
sway_length_peak	0.03	0.23	−0.24	**0.03**	0.27	0.06	−0.15	0.17	−0.14	0.14	−0.02	0.45	−0.02	0.44
sway_length_mean	0.05	0.15	−0.36	**0.00**	0.08	0.31	−0.21	0.09	−0.05	0.33	0.05	0.41	0.00	0.48
sway_length_SD	0.01	0.36	−0.26	**0.02**	0.21	0.11	−0.16	0.16	−0.09	0.24	−0.04	0.43	−0.01	0.45
sway_radius_peak	0.18	**0.00**	0.50	**0.00**	0.14	0.18	0.15	0.15	0.09	0.22	−0.08	0.33	−0.12	0.14
sway_radius_mean	0.14	**0.01**	0.41	**0.00**	0.12	0.16	0.15	0.08	0.01	0.43	−0.04	0.37	−0.11	0.07
sway_radius_SD	0.17	**0.00**	0.50	**0.00**	0.07	0.32	0.23	0.06	0.13	0.14	−0.13	0.25	−0.09	0.21

results were similar. Neither method found a significant effect of age on balance-related features. Among the static features with eyes open, the statistical test method did not find a significant effect of age, while some features showed a significant effect in the results of the regression analysis method. Most of these features are related to age, gender, and weight at the same time, that is, there exists interaction. For the static features with eyes closed, the results of both methods indicated that age was the most significant influencing factor, and showed consistent significant influence on most of the features.

3.3.2. Gender effect

In terms of pressure-related features, the statistical test method yielded more significant results than the regression analysis method. The reason for this is that pressure-related features are highly correlated with body weight, and there have differences in body weight between males and females. Among the time-related features, there was a significant difference in the contact time of the metatarsal region between the male and female groups. It was consistent between the two methods. Balance-related features were similar to pressure-related features, with weight being the most influential factor. Therefore, when the effect of gender on these features is considered, the regression analysis can eliminate the effect of weight, so the results are more reliable. On the static features of the open eye state, the significant influence of gender obtained by the two methods is completely consistent. It can be shown that gender may be the most important factor in such features. For the static features with eyes open, the conclusions about the effect of gender from the two methods are completely consistent. It can be shown that gender is the most important factor in such features. For the static features with eyes closed, both methods did not find many results showing significant effects, and only had certain effects on the COP velocity and acceleration related features.

4. Discussions

At present, most of the research on plantar pressure is usually aimed at special groups, while we mainly analyze the differences within the normal group, and study the influence of age, gender and other factors. We measured the plantar pressure data under walking and standing, so as to describe and analyze both dynamic and static aspects. Based on the plantar pressure, we extracted many features to describe the movement performance and gait characteristics of the human body. Through these features, some characteristics can be reflected intuitively. For example, the balance curves are extracted based on dynamic data to characterize the balance performance during walking; sway curves are extracted based on static data to characterize the degree of human shaking in a standing state. In our study, we not only compared the differences between different groups, but also considered the mixed effects of individual age, gender, height, weight, shoe size, and BMI from the perspective of individual differences. The ridge regression method, which can overcome the multicollinearity problem, is used, and the reliability of the method in multivariate analysis is also verified.

Through the analysis of plantar pressure features, we found that there exist certain differences in plantar pressure features between groups of different ages and genders, and these features are also affected by other factors. First of all, among the pressure-related features, weight and BMI are obviously the most influential factors. At the same time, age and gender have different degrees of influence on many features. These features represent the load-bearing and load conditions of different zones of the sole of the foot, thus revealing differences in the distribution characteristics of plantar pressure among different groups. For time-related features, there are no significant differences between the youth group and the old group, while males and females have significant differences in the metatarsal region, reflecting differences in gait characteristics between males and females. For balance-related features, we found that body weight is the most influential factor. The greater the body weight, the greater the difference in pressure between different zones, which means the worse the dynamic stability. In addition, age have no significant effect on these features, whereas balance-related features differed between males and females mainly in the metatarsal region. Combined with the differences in the contact time in the metatarsal region between males and females, it can reflect the difference in plantar physiological structure of different gender groups, and thus lead to different biomechanical characteristics. For the static features with eyes open, age, gender, weight, and BMI all have certain effects on some features, but no consistent conclusion was found. In the state of open eyes, the human body has better balance control ability, so the differences in static balance between different groups are difficult to reflect. In the closed eye state, there is a very clear difference between the youth group and the old group, and pointed to the same conclusion: the old compared with the youth, the static balance ability is worse. In addition, gender, weight, and BMI also have some effects on these features.

Our research shows the differences within normal groups, and these conclusions have certain reference value in related fields, such as: diagnostic assistance, rehabilitation evaluation, footwear design, etc. There are certain differences in the plantar pressure features between groups of different ages and genders. In addition, height, weight, shoe size, and BMI also have some effects. These factors cannot be ignored in the research and application of plantar pressure.

5. Conclusions

In this paper, we used the plantar pressure measurement system to analyze multi-factors to normal subjects in walking and static states. The plantar pressure data of 76 healthy subjects have been collected for analysis. Multi-features that can characterize the dynamic and static properties of human body from multiple aspects have been extracted and studied. We first divided the sample into groups by age and gender, and used statistical test method to analyze differences between young and old, and between males and females. Then, the ridge regression taking into account the height, weight, shoe size, and BMI has been carried out the multi-factor analysis. Based on the results of statistical test analysis, we found that there are differences in many features between groups of different ages and genders, which are further verified by regression analysis. It is found that height, weight, shoe size, and BMI also have some effects on the features of plantar pressure. These conclusions have certain reference significance for the research and application of plantar pressure.

CRediT authorship contribution statement

Shengkai Lin: Writing – original draft, Formal analysis, Writing – review & editing, Validation, Methodology. **Runze Zheng:** Data curation, Formal analysis, Conceptualization, Investigation, Methodology. **Weijie Zhao:** Supervision, Software, Validation. **Jiuwen Cao:** Supervision, Writing – review & editing, Methodology, Project administration, Funding acquisition. **Danping Wang:** Formal analysis, Investigation, Supervision, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Ethical statement

This study has been approved by the fourth Affiliated Hospital of Anhui Medical University registered in Chinese Clinical Trail Registry (PJ-YX2021-019). All patients gave their informed consent prior to their inclusion in the study.

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