Classification of lower limb body shapes of paralysed female wheelchair users in Hebei, China

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Lower limb body shape is important in the design of functional pants. The skin, muscles, and body shapes of the lower limbs of wheelchair users may differ from healthy people because of the different shapes of their legs and the prolonged seating position. This study aimed to classify the shapes of the lower limbs of adult female wheelchair users. The lower body measurement of 384 female wheelchair users was obtained. The principal component analysis and two-step cluster analysis were used to categorize the body shapes into three different types and five different size standards. Based on the study findings, female wheelchairs have larger waist, belly, and hip circumferences than healthy individuals, with 89.3% of them having prominent hips. Therefore, the design and production of trousers for wheelchair users should take into consideration the classification of lower limb shapes and sizes reported in this study.

Keywords: anthropometric; wheelchair users; paralysed female; lower body shape; functional trousers design

Introduction

In contrast to healthy individuals, paraplegic wheelchair users may develop unusual lower limb shapes due to prolonged sitting positions. For instance, due to the restricted leg mobility caused by paraplegia, the muscles in the lower extremities can undergo atrophy as early as one to three months after wheelchair usage, leading to a decreased leg circumference (Gantenbein et al., 2022). In addition, displacement of internal organs from their original positions due to abdominal tightening, gravity-induced sagging, and a rise in abdominal circumference can also be caused by diminished abdominal muscular strength (Sims, 2022).

In the current fashion design, the general size standards (GB/T1335.2-2007, ISO8559-2017) of the body shape and posture of the design objects are not a good fit for paraplegic wheelchair users. In other words, there is a shortage of wheelchairaccessible or appropriate clothing in the market today (Feng & Hui, 2022). In Chae's (2022) study of individuals with physical mobility problems, all ten interviewees reported that they were unable to find acceptable attires. Li et al. (2023) reported that the flexibility of clothing was the most frustrating problem encountered by wheelchair users as their bodies did not fit well in the apparels that they bought.

Well-fitting clothing is extremely important for the mental and physiological wellbeing of an individual because it acts as a skin-protection barrier against the environment and an external reflection of his/ her aesthetic taste (Esmail et al., 2020, Feng & Hui, 2021). According to Griggs and Vanheusden (2022), a slight rise in the temperature in the space between the skin and clothing can easily predispose paraplegic wheelchair users to stress injuries. For example, poorly-fitted trousers may squeeze the wearer's legs in the wrong places and prevent heat dissipation in the area. In addition, Lung et al. (2022) reported that the unnatural pressure distribution on the legs of wheelchair users may lead to unwanted effects on their blood flow and blood pressure, consequently resulting in deep vein thrombosis.

Psychologically, poorly-fitting clothing also prevents wheelchair users from expressing their feelings in an aesthetic and fashionable manner. This has been associated with an adverse impact on their mental and physical health (Silveira et al., 2023). Feng and Hui (2021) discovered that many of the current clothing designs for wheelchair users were not fashionable enough, thus affecting their self-confidence, especially in social participation. In a survey, Chae (2022) discovered that more than two-thirds of wheelchair users aged 20-60 years old said that their current clothing failed to fulfill their personal aesthetic expressive needs.

Based on the feedback of wheelchair users, it appears that manufacturers and retailers of fast fashion who primarily cater to the mass consumer market command overall control of the direction of the clothing industry (Linden, 2016). There is a lack of appropriate clothing from ready-to-wear brands for wheelchair users. Furthermore, customised clothing is prohibitively expensive, especially because the majority of physically-disabled people are of low income and rely on social welfare (Feng, 2022). Therefore, to enable the production of suitable and affordable clothing for wheelchair users, a complete set of basic clothing designs based on the sizes and standards of their lower limb shapes must be established. In this study, we set out to determine the leg vector characteristics of female wheelchair users. By measuring the body size of the legs of wheelchair users and classifying their morphological characteristics, a statistical model analysis was then performed to establish the size standards of the basic lower limb clothing pattern for them.

Methods

Participants

All subjects in this study were chosen through a combination of purposive sampling among registered members of the China Hebei Disabled Persons' Federation. The inclusion criteria were female paraplegics who had been using wheelchairs for more than a year as a result of a spinal cord injury. They must also display complete spontaneous breathing, unobstructed speech and expression, full or limited arm mobility in both directions, loss of motion below the waist that is accompanied by ectopic pain, and no evident pressure injury. The Cochran (1977) formula was used to calculate the sample size with an error level of 5% and a confidence interval of 95%. This technique was frequently used in other similar surveys (Talab et al., 2017). Ethical approval for this study was granted by Taylor's University Ethics Committee. A total of 384 female wheelchair users aged 25 to 35 years old from 11 prefectures and cities of Hebei

Province were recruited.

Selection of landmark

In this study, the landmarks of measuring position were selected in accordance with the International Standard Size Designation of Clothes (ISO 8559-2017) and the People's Republic of China's National Standard for Women's Wear Designation (GB/T1395.1-2007). A total of 11 measurement sites on the sitting position were taken for comparison (Figure 1). These sites were primarily selected based on the design and production requirements of tight trousers. The curved and straight lengths and dimensions of the human surface from the waist to the ankle were used as measurement landmarks. To reduce the measurement error, multiple measurements were performed.

Measurement protocol

The body dimensions of wheelchair users were measured using a direct method. Participants wore dark leggings during the measurement to protect their privacy. Measurements were taken in two positions, i.e. standing and sitting. As paraplegics cannot stand on their own, auxiliary suspension frames were used during posture measurements to keep their legs upright. Their carers also stood nearby to prevent any potential falls. They were asked to sit up as straight as possible during the sitting position to reduce the effect of body posture and chair size on the anthropometry measurements taken.

To ensure the consistency of the measurements being taken, all personnel were given standard training before the study. Measuring tools used included uniformly distributed tape measures to reduce the possible impact of production batches, storage temperature, and usage times on the accuracy of the measurements taken with the tape. Even though efforts were made to reduce errors, random errors might arise when the surveyor interpreted the values, i.e. the metrics from data entry. Missing or incorrectly entered data is the most common error when entering measurements into measurement protocols and again, when entering the data into the computer. Minor system errors can be caused by a single error during measurement and/ or reading from the measuring instrument. As a result, during the data collection process, the value of the data was also validated numerically and logically and any system error was promptly validated.

Data analysis

All data were recorded by the Excel software and imported into SPSS Statistics Version 27 for analysis. Cluster analysis was used to classify the lower limb morphology of female paraplegic wheelchair users. The analysis consisted of three steps: 1. standardised measurement, 2. cluster number determination, and 3. lower body type classification. Firstly, all manual direct measurements were taken with centimetres as the unit of measurement. To prevent errors caused by the movement of the tape measure and the change of body position during measurement, mark tape and mark points (Figure 2) were pasted on the designated body parts. Each measurement would be repeated three times and the average value represented the final measurement. Secondly, the Principal Component Analysis (PCA) method was used for data analysis whereby the principal components that were most affected by body shape changes were screened by the component matrix. Finally, a two-step cluster analysis was adopted in reference to the method used by Park et al. (2019) in studying the upper body sizes of Korean wheelchair users. Continuous variables were chosen for the cluster analysis and the Euclidean distance was employed to assess the distance. Finally, a Pivot Table was produced and the variables for the cluster members were established. A comparable discriminant function was created to categorise the types of lower bodies of wheelchair users.

Results

Anthropometric data

Table 1 shows the descriptive statistics of the body measurements. For example, the mean abdominal circumference was 82.1 cm with a standard deviation (SD) of 8.9 and a range of 62.0-120.0 cm.

Main indicators of the shapes of the lower body

In this study, PCA was used to analyse all the measurement data to identify the human body size with the largest influence on the size of the lower limbs. The results from the univariate descriptive and original analysis were retrieved and the coefficients, significance levels, determinants, KMO, and Bartlett's sphericity tests were selected from the correlation matrix of descriptive statistics. The molecular score was calculated using the regression method and the molecular score coefficient matrix was displayed. The rotation was performed using the maximum variance methodology.

Table 3 shows the results of KMO and Bartlett's sphericity tests, with KMO > 0.7 and Sig < 0.05 indicating a practical significance of the latitude reduction analysis of data. Based on the algorithm, the top three factors with Total > 1 were selected as the key components in Total Variance Explained (Table 4), with a cumulative coverage rate of 73.43% for all the data. The three components that were taken out of the Component Matrix were thigh length, joint circumference, and calf length (Table 4). In other words, the size from the groin to the knee cap, the size of the waist and hip circumference, and the size from the knee cap to ankle were the key factors influencing the lower limbs morphology of female paraplegic wheelchair users.

The classification of body size based on the lower limb measurements

The human body size included in the three principal components was used as the continuous variable in this study. A two-step cluster analysis was performed to precisely categorise the shapes of the participants' lower limbs (Kolose et al., 2021). The system automatically calculated the number of clusters (maximum of 15) and the distances were measured using the Euclidean approach. A clustering cost variable was created for the data file and the output pivot table was generated.

The samples were divided into five clusters (Table 6). The largest cluster included 338 participants, (88.0% of the total number of samples) while the other four clusters have 21, 12, 8, and 5 individuals, accounting for 5.5%, 3.1%, 2.1%, and 1.3% of the total number of participants respectively. The cluster distribution exhibited distinctive characteristics of similar types and distributions.

The PCA analysis also revealed that the main factors that determined the size of lower limbs were the length and circumference of the thigh as well as calf length. In this study, height, hip circumference, and calf length were applied as the representative molecules of each cluster, in addition to the human body size required in the design process of female trousers (Phasha et al., 2020). Figure 3 depicts the 3D scatter distribution result of the two-step clustering, with the five body types represented by circles of different colours. Table 7 shows the five classifications of the five size categories base on the data of lower body measurements obtained in this study. All results are reported in one decimal place.

Discussion

To develop a reference prototype for the trousers' design of female wheelchair users, their body types must first be considered. In the national recommendation of size standard used in China (GB/T1335.2-2008), only height, waist circumference, and leg circumference are included for pant size. Furthermore, there are no clear reference guidelines for the measurements of other human body parts. Previous research has refined the measurement technique by transforming two-dimensional human models into three-dimensional ones (Aluculesei et al., 2019). In addition, the extension of the body size of wheelchair users in spatial design was also measured (Adnan & Dawal, 2019; Rizo-Corona et al., 2020). However, the measurements of the body size of wheelchair users are still lacking. In this study, anthropometry measurement was performed to examine the body shapes of 384 female wheelchair users between 25 and 35 years old. These anthropometric measurements can be used to create prototype trousers and standard suit patterns using computer aid design (CAD) software.

Moreover, the manual measuring technique in this study was effective for data collection involving different body types of wheelchair users. All measurements are usually carried out in a wheelchair since the target population of paraplegics with spinal cord injuries cannot support themselves in a standing position. Furthermore, the armrest and high back of the wheelchair can be an obstacle in performing 3D scanning and photogrammetry. In this study, we successfully applied the manual measuring approach in this investigation. The lower limb of wheelchair users was measured in segments according to the predefined landmarks to accurately classify the body size based on the lower limb measurements. This method can stretch the skin on the body surface.

Similar to ISO 8559 and GB/T 1335.2-2008, this study used anthropometric height and waist circumference as the reference standard values in categorising human body types to facilitate the wearers in deciding the appropriate apparel size for their body types. Five virtual human models with various body types are displayed in Table 8.

Using XS 158/92 as an example, XS stands for extra tiny body type and includes individuals who are 158.3±3.3 cm in height and 92.3±7.3 cm in waist circumference.

For each height category, the size specifications were compared with the Chinese national size standard as the reference value (Table 9). Wheelchair users generally showed larger waist and hip measurements than healthy individuals who can maintain a standing position. The largest difference in body size was observed for the size XS 158/92, with the height being 1.1% lower and the waist circumference being 35.4% higher than the standard body size. This body type accounted for 5.5% of the total sample size. For L 170/74, only five wheelchair users (2.1% of the total population) in the group recorded waist-hip circumferences that were smaller compared to the standard body size. Based on the body curvatures, the five body sizes can be further categorised into three groups, i.e. ventral convex, hip protruding, and slim. The ventral convex body types (such as XS 158/92 and M 169/93) usually have larger waist and abdominal circumferences than other body sections. The hip protruding shape includes S 161/70 and XL 172/75. Compared to the ventral convex body type, the hip protruding body type does not show any significant increase in waist circumference but their hips are more prominent. As for L 170/74, the individuals have longer bodies and no apparent curvatures in any area, thus being classified as the slim type.

There are certain limitations to this study. Firstly, the participants only included paraplegic women in manual wheelchairs in the Hebei Province, China. Spinal cord injuries, primarily on the thoracic to lumbar vertebrae, were the main cause of the individuals' disabilities. Thus, the results may not be generalisable to other people such as those who use electric wheelchairs or live in other areas.

Conclusion

The anthropometric characteristics of female wheelchair users identified in this study will be useful for industrial producers and fashion retailers of female trousers. It is critical to distinguish between the dimensions of lower body forms of wheelchair users and healthy people because waist, abdominal, and hip circumferences can affect the sizes, styles, and designs of trousers. The design scheme of trousers will also directly affect the fitting of the trousers (Zakaria & Ruznan, 2020). As a step forward, future research can evaluate the amount of stretch and relaxation in the trousers. It will also be necessary to adapt the design of industrial pattern-making and processing lines to produce clothing that is suitable to the body types of female wheelchair users. A reduction in production costs can improve the efficiency of clothing production for people with special needs.

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Table 1. Summary of anthropometric data (n= 384).

			Circumferences (cm)				
	Height (cm)	Weight (cm)	Waist	Abdominal	Hip	Knee	Thigh
Mean	161.6	54.7	73.0	82.1	97.6	38.5	51.8
SD	4.2	8.0	8.4	8.9	7.5	3.2	6.2
Max	178.0	105.0	105.0	120.0	128.0	57.0	71.0
Min	153.0	37.0	56.5	62.0	80.0	31.0	38.0

Table 2. Summary of lower limb measurement data (n= 384).

	Height of hip (cm)	Navel to the groin (cm)	Groin to knee cap (cm)	Knee to the ankle (cm)	Hip to popliteal (cm)	Popliteal to the ankle (cm)
Mean	22.5	10.7	39.5	46.0	50.4	35.4
SD	2.2	1.6	4.1	3.8	4.1	3.5
Max	27.5	14.5	56.0	58.0	67.0	47.0
Min	13.5	8.0	31.0	30.0	42.0	28.0

Table 3. KMO and Bartlett's test.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.759
Bartlett's Test of Sphericity	Approx. Chi-Square	3644.173
	df	66
	Sig.	.000

Table 4. Total variance explained.

Total Variance Explained

Component	Initial Eigenvalues Total	Initial Eigenvalues % of Variance	Initial Eigenvalues Cumulative %	Extraction Sums of Squared Loadings Total	Extraction Sums of Squared Loadings % of Variance	Extraction Sums of Squared Loadings Cumulative %
1	3.750	31.247	31.247	3.750	31.247	31.247
2	3.350	27.914	59.161	3.350	27.914	59.161
3	1.713	14.272	73.433	1.713	14.272	73.433
4	.902	7.521	80.953			
5	.640	5.332	86.285			
6	.523	4.356	90.641			
7	.369	3.078	93.719			
8	.282	2.352	96.071			
9	.179	1.489	97.560			
10	.158	1.316	98.876			
11	.101	.842	99.718			
12	.034	.282	100.000			

Extraction Method: Principal Component Analysis.

Table 5. The results of the component matrix.

Component Matrix[a]

	Component 1	Component 2	Component 3
Hight	.894	-.296	-.166
(Si) Waist Circumstance	.370	.832	.081
(Si) Abdomen Circumstance	.299	.822	.019
(Si) Hip Circumstance	.290	.794	-.052
(Si) Knee Circumstance	.357	.655	-.001
(Si) Thigh Circumstance	.212	.698	.064
(Si) The Hight of Hip	.737	-.194	-.192
(Si) Navel to Groin	.373	-.208	-.278
(Si) Groin to Knee Cap	.883	-.323	-.156
(Si) Knee to ankle	.357	-.175	.874
(Si) Hip to Popliteal	.864	-.302	-.146
(Si) Popliteal to ankle	.360	-.199	.865

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

Table 6. Cluster distribution.

Cluster Distribution

		N	% of Combined	% of Total
Cluster	1	338	88.0%	88.0%
	2	5	1.3%	1.3%
	3	8	2.1%	2.1%
	4	12	3.1%	3.1%
	5	21	5.5%	5.5%
	Combined	384	100.0%	100.0%
Total		384		100.0%

Table 7. Cluster profile.

Cluster			**1**	**2**	**3**	**4**	**5**
Centroids	**Height**	Mean	**161.2**	**171.6**	**170.3**	**169.4**	**158.3**
		SD	3.6	3.6	4.0	2.2	3.3
	Waist Circumference	Mean	71.0	75.0	74.4	92.8	92.1
		SD	5.5	.0	7.8	10.3	7.3
	Abdominal Circumference	Mean	80.1	81.6	83.2	97.6	104.8
		SD	6.1	1.3	3.8	11.0	8.8
	Hip Circumference	Mean	**96.3**	**103.4**	**94.4**	**110.8**	**110.8**
		SD	6.2	3.6	4.2	9.6	5.2
	Knee Circumference	Mean	37.8	43.6	41.6	42.6	43.1
		SD	2.7	.9	4.6	2.2	2.6
	Thigh Circumference	Mean	51.1	52.8	48.4	54.3	62.8
		SD	5.5	4.9	5.0	6.2	7.1
	Height of Hip	Mean	22.5	24.4	25.1	24.6	20.8
		SD	2.2	2.2	1.0	1.4	2.3
	Navel to Groin	Mean	10.8	8.4	12.3	11.5	9.4

		SD	1.6	.9	1.1	1.2	1.2
	Groin to Knee Cap	Mean	39.1	49.6	46.6	47.1	35.9
		SD	3.4	3.6	2.7	1.9	2.8
	Knee to ankle	Mean	**46.0**	**47.6**	**43.9**	**45.9**	**46.2**
		SD	3.8	.2	2.2	2.7	3.3
	Hip to Popliteal	Mean	50.0	59.8	55.3	57.7	47.0
		SD	3.6	1.8	5.5	2.1	3.1
	Popliteal to ankle	Mean	35.3	37.6	32.9	34.9	35.9
		SD	3.6	2.5	2.2	2.7	2.9

Table 8. Lower body shape identity.

XS 158/92	S 161/71	M 169/93	L 170/74	XL 172/75
Cluster 5	Cluster 1	Cluster 4	Cluster 3	Cluster 2

Table 9. The size comparison between wheelchair users and the national standard.

Size	GB/T 160/68A	XS 158/92	S 161/70	GB/T 170/76A	M 169/93	L 170/74	XL 172/75
Height	160.0	158.3 (-1.1%)	161.2 (0.8%)	170	169.4 (-0.4%)	170.3 (0.18%)	171.6 (0.94%)
Waist Circum-ference	68.0	92.1 (35.4%)	71.0 (4.4%)	76.0	92.8 (22.1%)	74.4 (-2.1%)	75.0 (-1.0%)
Hip Circum-ference	90.0	110.8 (23.1%)	96.3 (7%)	97	110.8 (14.2%)	94.4 (-2.7%)	103.4 (6.6%)

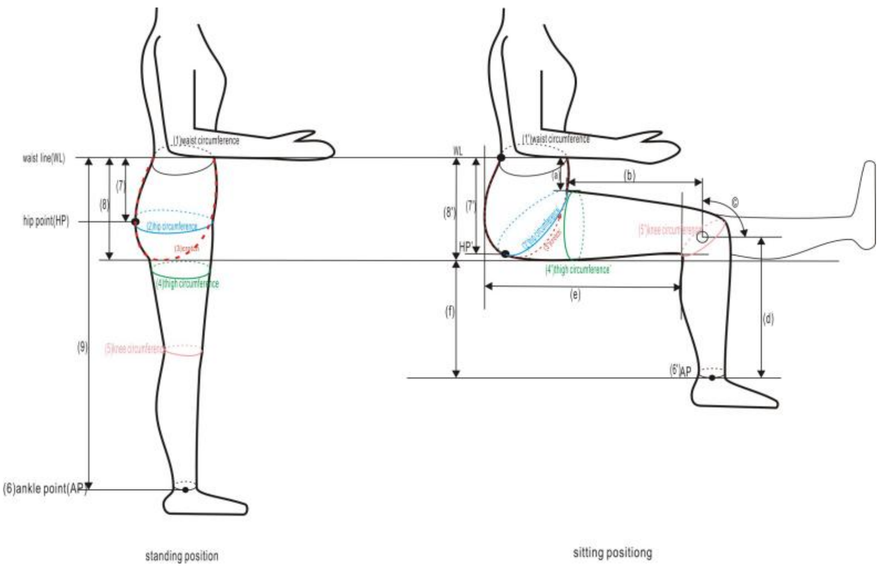

Figure 1. Measurement landmarks for different positions.

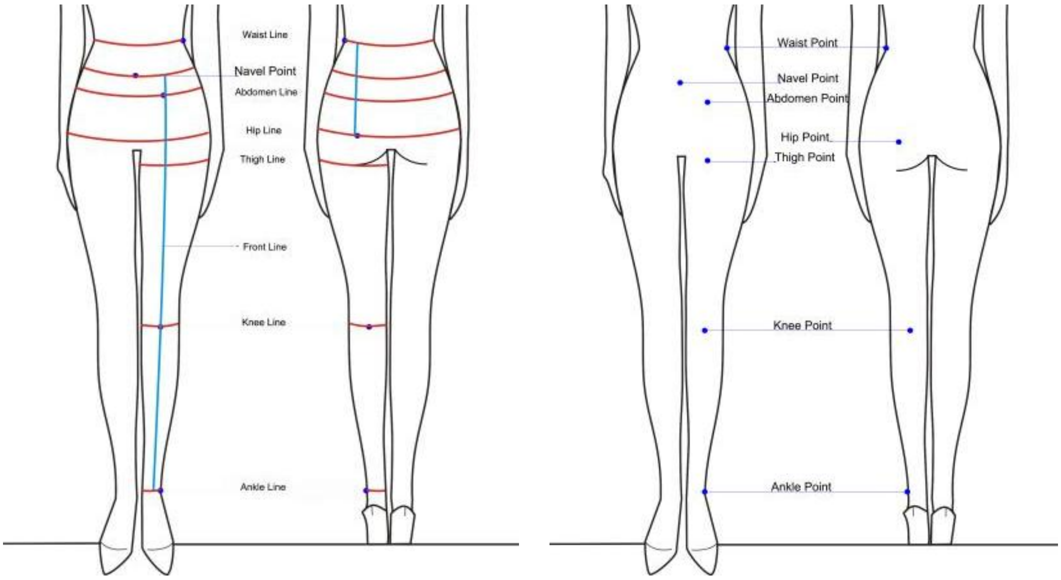

Figure 2. Marking lines and marking points.

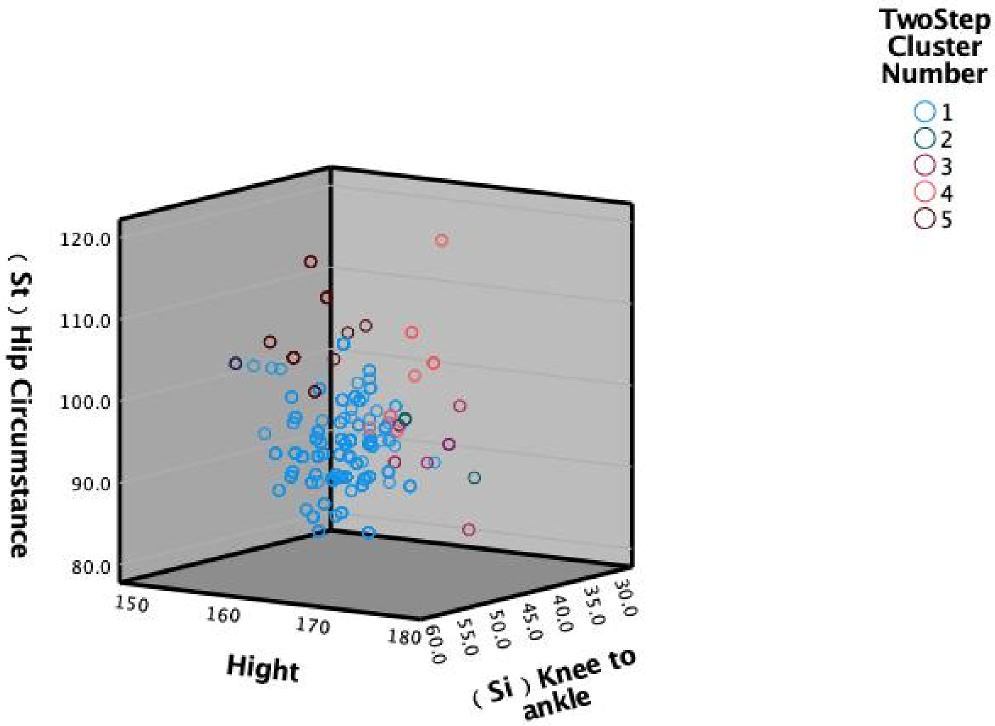

Figure 3. Scatter map showing the lower limb shapes in the sitting position.