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2019 Mathematical Contest in Modeling (MCM) Summary Sheet
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A Balance Ability Evaluation System for Seniors

Summary

Currently, population aging is a problem that many countries around the world are facing. At the same time, accidental falls, one of the most common health hazards, are threatening the elderly all the time. Elderly people are far more likely to fall unexpectedly as their balance ability deteriorates. Therefore, it is of great practical significance to assess the balance ability of the seniors. To address this situation, we establish a balance ability evaluation system for seniors.

The first stage, we divide the balance characteristics of the test subjects into two categories by visualizing the 3D motion data of the test subjects. One is gait balance and the another is body movement balance. On this basis, we establish a feature extraction model combining the gait model and the 3-dimension Human Walking model. We extract 12 gait balance characteristics through the parameters of the gait model, and then use the 3-dimension Human Walking model to match the key points of the Human body with the monitoring points of the key points. The motion angle and the offset of the center of gravity of the 12 joints in the space are selected as the motion balance characteristics of the body.

The second stage, we establish the rank-sum ratio comprehensive evaluation method model based on the entropy weight method to determine the weight. According to the size of the weighted rank-sum ratio, we rank 76 test subjects. The results show that Tongsheng Li is the most likely to fall, while Juan Zhao is the least likely. Then we draw the right view of the actual walking condition of the two subjects. In combination with the index weight and the actual walking condition, we give suggestions to the seniors with high risk of falling from three aspects: walking speed, the height of left foot lift and the angle of joint change.

The third stage, after washing and screening the basic data of the elderly, we select five level-1 indicators such as age, BMI, number of falls, number of diseases, and aid by hand or not. Based on the classification and scoring of each index, we constructed the balance ability assessment scale for the elderly. We compare and analyze the elderly with different levels of balance ability within and between groups, and provide effective suggestions for the elderly with poor balance ability.

Remarkably, we test the rank-sum ratio comprehensive evaluation method model. We analyze the sensitivity of the weight of each index. The results show that when the weight is changed by 5%, the change of ranking result is less than 20%. Furthermore, when the weight is increased, the accuracy of balanced risk assessment for the elderly gradually decreases. In addition, we find that the swing of the right arm does not affect the results of the model.

Contents

1 Introduction

1.1 Problem Background

Falling is one of the common health problems among the elderly population. According to the U.S. Centers for Disease Control and Prevention (CDC), about one-third of people over the age of 65 fall more than once a year, and the proportion increases with age. [1] This incidence increases to 66% for ambulatory residents of nursing homes. [2] The annual incidence of falls over 80 years old can be as high as 40%. Falling not only makes the elderly feel fear and anxiety, but about 5% to 15% after the fall will lead to brain damage, soft tissue damage, fractures, dislocation and other complications. [3] At the same time, due to the generally poor rehabilitation capacity, the fall will further deteriorate elderlys life quality.

In fact, falls are the first indirect cause of death for people over the age of 65. [4] Falls threaten seniors' safety and independence and generate enormous economic and personal costs. Therefore, it is of great practical significance to assess the balance ability of the elderly to help the elderly to master the state of motion, correct the improper position and prevent accidental falls.

1.2 Previous Research

At present, more and more countries are entering an aging society, especially in European countries, the problem of population aging is particularly serious. As advances in medicine and public health services have improved people's overall lives, scientists predict that the proportion of people over the age of 60 will increase from the current 10% to 22% over the next 50 years. [5] Elderly people are weaker and are prone to stroke, diabetes and bone diseases. These diseases impair their balance, reduce their weight shifting ability, increased their postural sway, and decrease their stance capability. [6] At the same time, the intake of various drugs due to the disease have additional physical effects on seniors.

Among the elderly population, the fall is the most common type of accident, which can lead to various complications such as depression, reduced social activity, poor quality of life, and even severe fractures or death. Therefore, the study of the fall of the elderly is an important issue.

By assessing the balance of the elderly, it is of great significance to help the elderly correct their posture and prevent falls. Aline H. Karuka1, José A. M. G. Silva and Marcelo T. Navega conducted a different degree of physical condition survey of 30 healthy women living in the community, and passed the test to arrive at the Functional Reach Test (FRT), the Berg Balance Scale (BBS), the Timed Up and Go (TUG) and the Performance-Oriented Mobility Assessment of Balance (POMA). [7]

Data analysis was performed using the Spearman correlation coefficient to assess the body balance ability of the elderly. N. Amritha and Menon M. Mahim have designed an economical and efficient system that provides static and dynamic balance training through virtual reality interactive games to help patients improve their body balance and coordination. [8] Literature [9] studied the pressure distribution under the six positions of the soles of the elderly, and analyzed the measured data using the maximum force, peak pressure, mean pressure and contact area, and proved the auxiliary effect of the walking aid on walking gait and posture.

We discover that most of the literature only selects a certain area of the human body to study the balance ability. In this regard, we consider the selection of multiple physical characteristics from the whole body based on the human body's stepping, center of gravity and motion, in order to conduct a comprehensive physical balance assessment for the elderly.

1.3 Our Work

- We analyze the balance features of elderly people based on the data in Annex 2. Based on that, we construct a feature extraction model made up of 25 features and analyze the steps, the center of gravity and motion.
- We build a balance risk assessment system based on 25 indicators to assess the balance ability of elderly people, and give some reasonable advice accordingly.
- We address an analog computation and a comparative analysis of the body balance force based on the actual data provided. Whats more, we give some effectual suggestions to seniors with poor balance ability.

2 Key Points Analysis

2.1 Analysis of 42 Monitoring Points

There are many aspects to a balanced body. Based on the 3d data of 42 monitoring points, we can simulate the walking of the test subjects.25 body balance characteristics were extracted by analyzing the subjects' walking gait and body movement.

2.2 Analysis of Falling Risk

The risk of falls in older people is closely related to their ability to balance. A comprehensive evaluation model is established based on the 25 equilibrium indexes extracted from Question I.The results were used to effectively assess the risk of falls. In the process of comprehensive evaluation model, the appropriate weight can make the evaluation result more practical.

2.3 Comparative Analysis of the Body Balance Force

For the basic data of the elderly in Annex 1, we need to screen out indicators related to the balance ability through data mining, so as to obtain the actual balance ability of each elderly body.

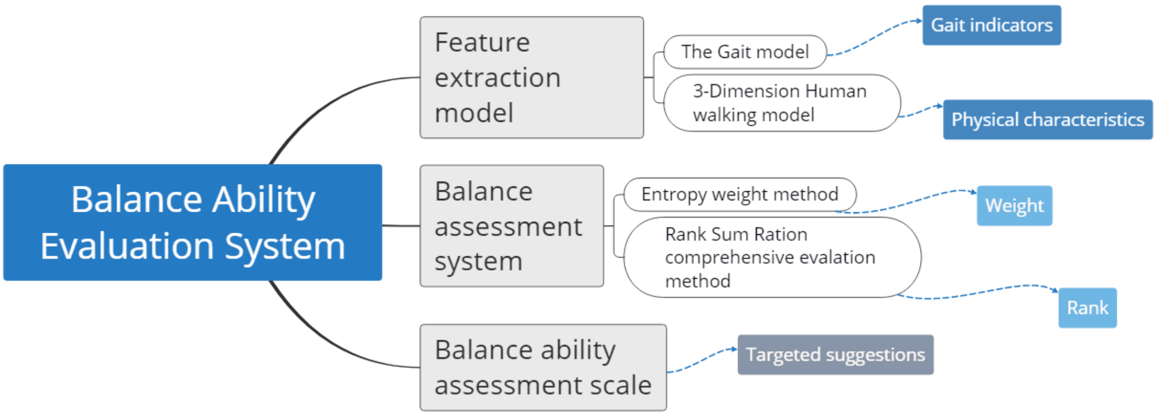


Figure 1: Modeling Ideas Mind Maps

3 Generall Assumption

To simplify the problems, we make the following basic assumptions, each of which is properly justified.

- Assumption 1: The elderly people are assumed to walk with their heels off the ground and their heels on the ground.
- Assumption 2: To simplify the calculation, we use the average value to replace the instantaneous value.
- Assumption 3: The classification scores given in the balanced assessment scale according to expert advice are true and valid.

4 Symbols and Definitions

In the section,we use some symbols for constructing the model as follows, other symbol instructions will be given in the text.

Table 1: Symbols and Definitions

Symbols	Meanings
Sl_R	Right step length
Sl_L	Left step length
$Sl_{average}$	Average stride length
Sw	Step width
θ_R	Right toe out angle
θ_L	Left toe out angle
Ct	Cycle time
S	Pace
H_R	Lifting height of right heel
H_L	Lifting height of left heel
T_{Mstand}	Average stand phase
T_{Mswing}	Average swing phase
$\Delta\theta_i, i = 1, 2, ..., 12$	Amplitude of limb movement
ΔG	Amplitude of center of gravity movement
RSR	Rank Sum Ration

5 Feature Extraction Based on the Gait and the 3DHW Model

5.1 Modeling Ideas

Through the visualization processing of the three-dimensional data in Annex II, combined with relevant literature, we find that the changes of gait, the fluctuation of center of gravity and the movement of limbs affect the body balance. We first extract 12 gait features by using the Gait model. [10] Then, by using Three-Dimension Human Walking (3DHW) model, [11] we abstract the human body as a rigid body connected with each other. On this basis, the position of gravity center and the angle of 12 joints in space are extracted as the characteristics of body movement. Finally, we extract 25 body features for a comprehensive body balance assessment for elderly people.

5.2 Data Visualization

We extract 19 joint nodes from the 42 monitoring points. Then, we select four time points in the whole movement process and use MATLAB to simulate the walking posture of the elderly body. The simulation results of Aizhen Jiang in Annex II are shown in **Figure 2**.

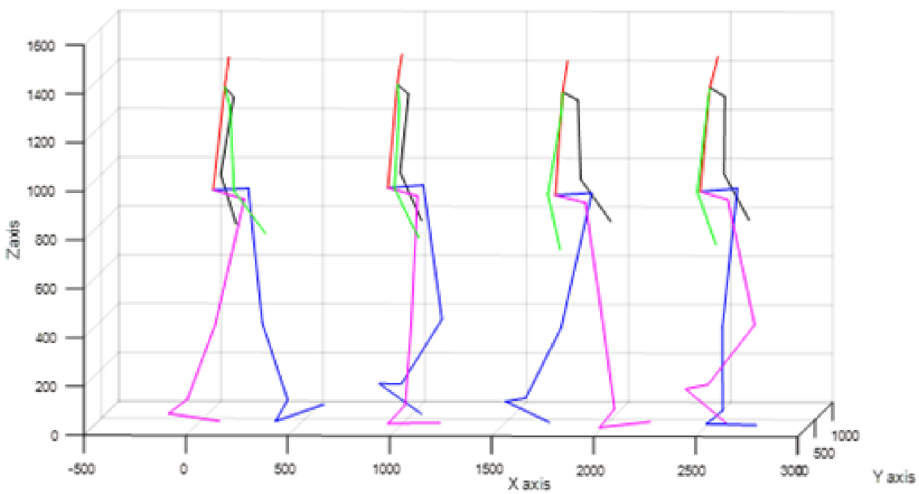


Figure 2: Simulation of Walking Posture

5.3 Feature Extraction

5.3.1 Extraction of Gait Features

The Foot Print method is one of the earliest and simple methods of kinematic gait analysis. On that basis, we establish a gait feature extraction model as follows.

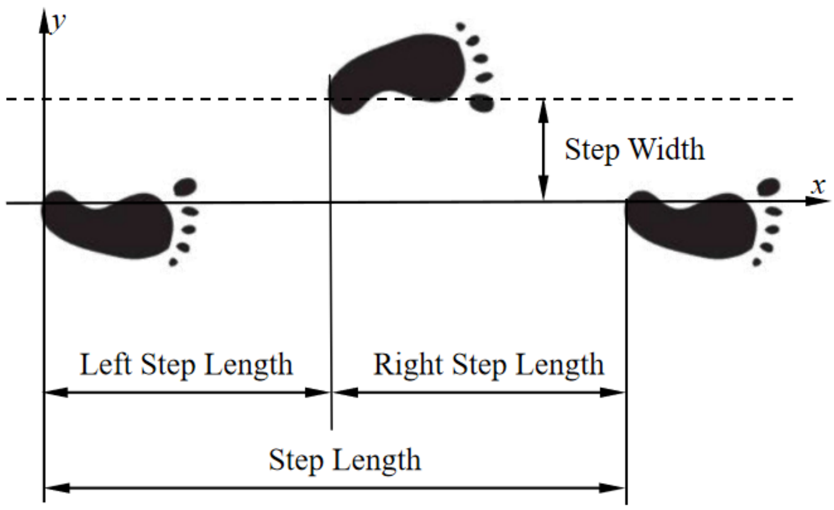


Figure 3: Foot Print Features

1.Left/ Right Step Length

As shown in **Figure 3**, take the calculation of right step length Sl_R as an example,

$$Sl_R = \frac{1}{n}\sum_{i=1}^{n}(X_{R(i)} - X_{L(i)}), \tag{1}$$

where n is the number of walking steps, $X_{R(i)}$ and $L_{R(i)}$ are the position of the right heel and the left heel in the forward direction, respectively.

Similarly, the left step length can be obtained. If one foot is always behind the another while walking, the step length is negative.

2.Average Step Length

The step length is the distance between two consecutive footprints of the same foot on the ground. Considering the inconsistency of the left and right steps length of each person, we use the sum of the left and right steps instead of the average step length $Sl_{average}$. So we have:

$$Sl_{average} = Sl_R + Sl_L. \tag{2}$$

3.Step Width

Step width Sw refers to the distance between the midpoints of two heels, which can be denoted as follows:

$$Sw = \frac{1}{n}\sum_{i=1}^{n}[Y_{L(i)} - \frac{1}{2}(Y_{R(i)} + Y_{R(i+1)})], \tag{3}$$

where

- $Y_{R(i)}$ is the vertical coordinate of the right heel at time $t_{R(i)}$,
- $Y_{R(i+1)}$ is the vertical coordinate of the right heel at time $t_{R(i)}$,
- $Y_{L(i)}$ is the vertical coordinate of the left heel at time $t_{L(i)}$.

4.Toe Out Angle

As shown in **Figure 4**, the toe out angle refers to the angle formed by the center line of the sole of the foot and the advancing direction. The spatial coordinates of monitoring points 34 and 36 are respectively, thus the toe out angle of right foot θ_R can be written as:

$$\theta_R = \frac{1}{n}\sum_{i=1}^{n} \arctan\frac{y_{34}^i - y_{36}^i}{x_{34}^i - x_{36}^i}. \tag{4}$$

Similarly, the toe out angle of left foot θ_L is written as:

$$\theta_L = \frac{1}{n}\sum_{i=1}^{n} \arctan\frac{y_{35}^i - y_{37}^i}{x_{35}^i - x_{37}^i}. \tag{5}$$

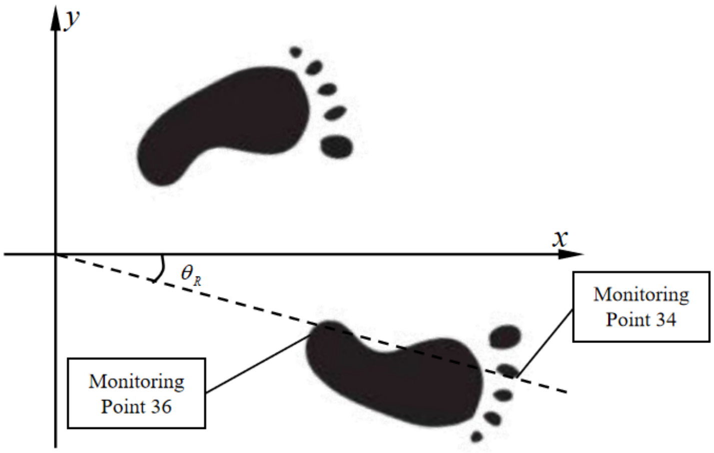


Figure 4: Right Toe out Angle

5.Cycle Time

Cycle time Ct refers to the time elapsed from the time when one leg follows the ground to the time when the heel of that leg lands again. The cycle time is given by:

$$Ct = \frac{1}{n}\sum_{i=1}^{n}[\frac{1}{2}(T_R^{i+1} - T_R^i) + \frac{1}{2}(T_L^{i+1} - T_L^i)], \tag{6}$$

where

- T_R^i is the i^{th} landing time of the right heel,
- T_R^{i+1} is the $(i+1)^{th}$ landing time of the right heel,
- T_L^i is the i^{th} landing time of the left heel,
- T_L^{i+1} is the $(i+1)^{th}$ landing time of the left heel.

6.Speed

Since we have the step length $Sl_{average}$ and the cycle time Ct, the speed S can be written as:

$$S = Sl_{average}/Ct. \tag{7}$$

7.Lifting Height

The lift height H denotes the height difference between the maximum height H_R^{max} and the minimum height H_R^{min} of the heel during walking. The lifting height of right foot H_R is given by:

$$H_R = H_R^{max} - H_R^{min}, \tag{8}$$

and the lifting height of left foot is:

$$H_L = H_L^{max} - H_L^{min}. \tag{9}$$

8.Average Stand Phase

The stand phase T_{MStand} indicates the time during which a unilateral lower limb is in contact with the ground during a gait cycle.[12]Analyzed the walking data records of the subjects, we find that the stand phase of left leg and that of right leg are different. Therefore, we use the average value of the left and right stand phases in each gait cycle to measure T_{MStand}:

$$T_{MStand} = \frac{1}{n}\sum_{i=1}^{n}[\frac{1}{2}(t_{Roff}^{i} - t_{Rdown}^{i}) + \frac{1}{2}(t_{Loff}^{i} - t_{Ldown}^{i})], \tag{10}$$

where t_{Rdown}^{i} and t_{Ldown}^{i} are the landing time of right and left heel respectively in the i^{th} gait, t_{Roff}^{i} and t_{Loff}^{i} are the lifting time of right and left heel respectively in the i^{th} gait.

9.Average Swing Phase

The average swing phase T_{MSwing} illustrates the time during which a unilateral lower limb swings in the air during a gait cycle. With reference to **8.**,we have:

$$T_{MSwing} = \frac{1}{n}\sum_{i=1}^{n}[\frac{1}{2}(t_{Rdown}^{i+1} - t_{Roff}^{i}) + \frac{1}{2}(t_{Ldown}^{i+1} - t_{Loff}^{i})], \tag{11}$$

where the parameter meaning is the same as in formula (10).

5.3.2 Feature Extraction Model Based on 3DHW

In order to make the description of the balance characteristics of walking of human body more uniform, we select 12 joints from 3DHW model parameters as the motion characteristics of the limbs in space. After approximately matching the layout of the 42 monitoring points, we establish the improved human walking model made up of 19 monitoring points, as shown in **Figure 5**.

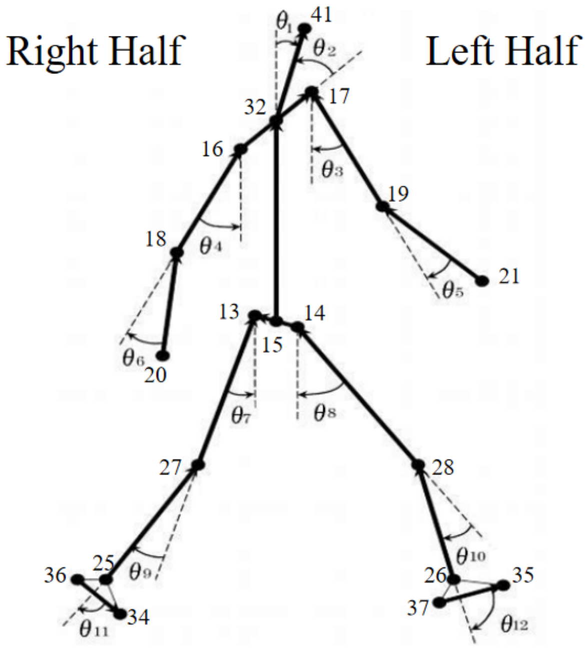


Figure 5: Improved Human Walking Model Based on 3DHW

1.Amplitude of Limb Movement

As indicated in **Figure 5**, the coordinates of each monitoring point are marked as follows:

$$P_i(x_i, y_i, z_i), i = 1, 2, ..., 42.$$

For each $\theta_i (i = 1, 2, ..., 12)$ in **Figure 5**, it changes according to the changes of the 19 monitoring points. Take θ_1 as an example, we have:

$$\theta_1 = \arccos \frac{(x_{41} - x_{32}, y_{41} - y_{32}, z_{41} - z_{32}) \cdot e_z}{|(x_{41} - x_{32}, y_{41} - y_{32}, z_{41} - z_{32})|}, \tag{12}$$

where $e_z = (0, 0, 1)$ is the unit vector in the vertical direction.

Since θ_1 changes constantly in the process of movement, the range of limb movement $\Delta\theta_1$ is measured by the difference between the maximum value θ_{1max} and the minimum value θ_{1min} in the process, that is:

$$\Delta\theta_1 = \theta_{1max} - \theta_{1min}. \tag{13}$$

2.Amplitude of Center of Gravity Movement

Based on the 3DHW model, we use the improved algorithm of the torque synthesis algorithm to multiply the coefficient method to extract 17 key points, the corresponding key point coefficients k_i are shown in **Table 2**. The position of center of gravity can be denoted as:

$$G_y = \sum k_i y_i, \tag{14}$$

$$G_z = \sum k_i z_i, \tag{15}$$

where G_y and G_z are the position of the center of gravity in the y and z directions respectively.

Table 2: Key Points and Corresponding Coefficients

Key Points(Corresponding Monitoring Points)	Coefficients(k_i)
Head(41)	0.0706
Shoulder(16,17)	0.0356
Midpoint of the Shoulder Line(32)	0.2391
Elbow(18,19)	0.0580
Wrist(20,21)	0.0192
Hip(13,14)	0.1297
Midpoint of the Hip Line(15)	0.1879
Knee(27,28)	0.1630
Ankle(25,26)	0.0643
Heel(36,37)	0.0158

We describe the amplitude of the center of gravity of the center of gravity ΔG as the resultant offset Δy in the y direction and the arithmetic mean of the maximum offset Δz in the composite offset of the maximum offset in the z direction. Therefore, we have:

$$\Delta G = \frac{1}{2}\Delta y + \frac{1}{2}\Delta z. \tag{16}$$

5.4 Sum up

On the basis of the gait model and the 3DHW model, we obtain the following 25 balance features of elderly people.

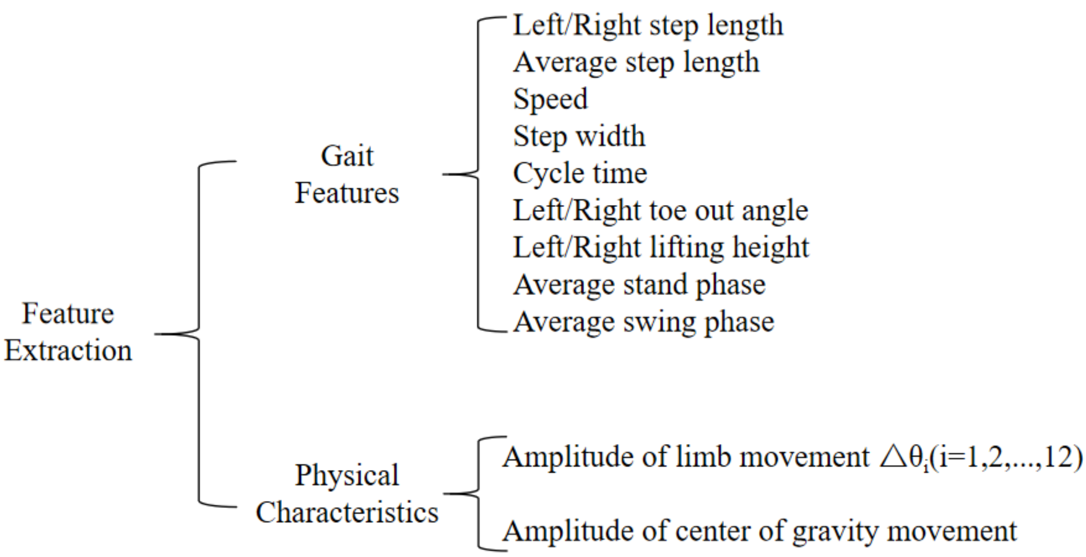


Figure 6: Feature Extraction Results

6 Entropy Weight - RSR Method Comprehensive Evaluation System

6.1 Modeling Ideas

Based on the 25 indicators extracted from Question I, we obtain the raw data of indicators of 76 seniors. Using the Entropy Weight Method, we determine the weight of each indicator. Then we use the comprehensive evaluation method of Rank Sum Ration (RSR) to construct a balance assessment system.

6.2 The Establishment Process of Assessment System

In the process of establishing the evaluation system, the weight of each indicator is our primary consideration. Since each indicator data is calculated on the basis of the formulas in Question I, and the information contained therein can better reflect the balance of the body, we use the Entropy Weight method to determine the weight of each indicator.

6.2.1 Determining Indicator Weights by Entropy Weight Method

Since we have m items to be evaluated and n evaluation indicators, the raw data matrix $r=(r_{ij})_{m\times n}$ can be written as:

$$r=\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix}_{m\times n},$$

where r_{ij} is the evaluation value of the i^{th} item under the j^{th} indicator.

The steps to use Entropy Weight method are as follows:

Step 1: Calculate the proportion p_{ij} of the evaluation value of the i^{th} item under the j^{th} indicator:

$$p_{ij} = r_{ij}/\sum_{i=1}^{m} r_{ij}. \tag{17}$$

Step 2: Determine the entropy value e_j of the j^{th} indicator:

$$e_j = -k\sum_{i=1}^{m} p_{ij}\cdot \ln p_{ij}, \tag{18}$$

where $k = 1/\ln m$.

Step 3: Confirm the entropy weight ω_j of the j^{th} indicator:

$$\omega_j = (1 - e_j) / \sum_{j=1}^{n} (1 - e_j). \tag{19}$$

The partial weight result table is shown in **Table 3**: (in descending order of weight)

Table 3: Indicators and Corresponding Weights

Indicators	Weight ω_j
S	0.277
H_L	0.108
$\Delta\theta_1$	0.066
$\Delta\theta_{10}$	0.051
...	...
$\Delta\theta_8$	0.029
θ_R	0.028
$\Delta\theta_7$	0.026
T_{MSwing}	0.025
...	...
Sl_R	0.014
θ_6	0.012
Sl_L	0.007
$\theta_1 1$	0.004

6.2.2 Construction of RSR Comprehensive Evaluation System

1.Principle

We obtain a dimensionless statistic RSR by rank transformation in a n-row m-column matrix. On this basis, we use the concept and method of parametric statistical analysis to study the distribution of RSR, and the balance ability of the seniors is directly sorted or sorted by RSR, so that the evaluation object can be comprehensively evaluated.

2. Concrete Steps

Step 1: Compile the ranks of each evaluation object of each index, wherein the benefit type index is compiled from small to large, the cost type index is compiled from large to small, and the same indicator data is averaged. The resulting rank matrix is denoted as $R = (R_{ij})_{m\times n}$.

Step 2: Calculate the weighted rank sum ratio (WRSR). The weights of each indicator are determined based on the entropy weight method, and the weighted rank sum ratio is calculated by the formula (20).

$$WRSR_i = \frac{1}{n}\sum_{j=1}^{m}\omega_j R_{ij}, i = 1, 2, ..., n. \tag{20}$$

Step 3: Compile the WRSR frequency distribution table in ascending order. First list the frequency f_i of each group. Second, calculate the cumulative frequency cf_i of each group and determine the cumulative frequency $p_i = cf_i/n$. Then convert p_i into a probability unit $Probit_i$, which is a standard normal distribution of quantiles plus 5.

Step 4: Calculate the linear regression equation as the formula (20) with the probability unit $Probit_i$ corresponding to the cumulative frequency as the independent variable and the $WRSR_i$ value as the dependent variable:

$$WRSR = a + b \times Probit, \tag{21}$$

where a and b are coefficients.

Step 5: According to the estimated value corresponding to the regression equation (21), sort the evaluation object by step.

6.3 Evaluation Results

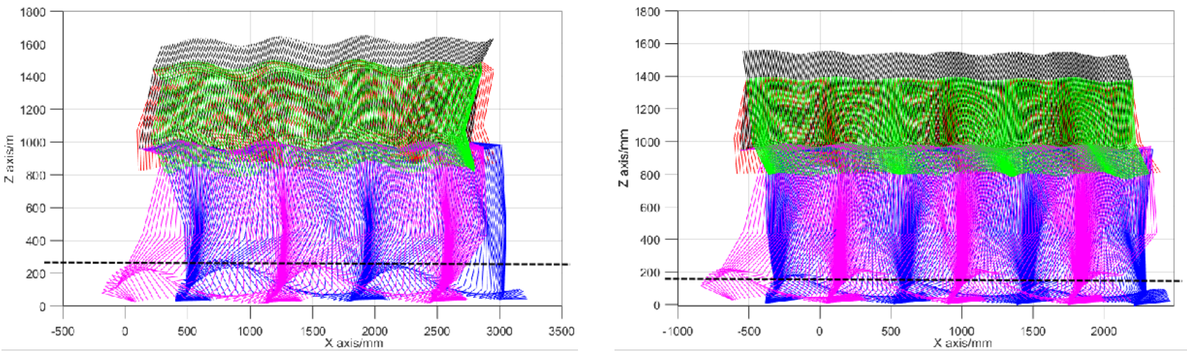
We use MATLAB to find the sequence results, as shown in **Table 4**.

Table 4: Evaluation Results of the 76 Test Takers

Name	$WRSR$	Rank
Tongsheng Li	0.762	1
Wenlong Li	0.744	2
Zhining Wang	0.739	3
Keqin Zong	0.727	4
Yubin Hao	0.714	5
...	...	...
Shurong Zhao	0.291	72
Chunling Wang	0.284	73
Chengyu Yang	0.282	74
Xiulan Cui	0.281	75
Juan Zhao	0.230	76

As can be seen from **Table 4**, Tongsheng Li is the most likely to fall, while Juan Zhao is the least likely.

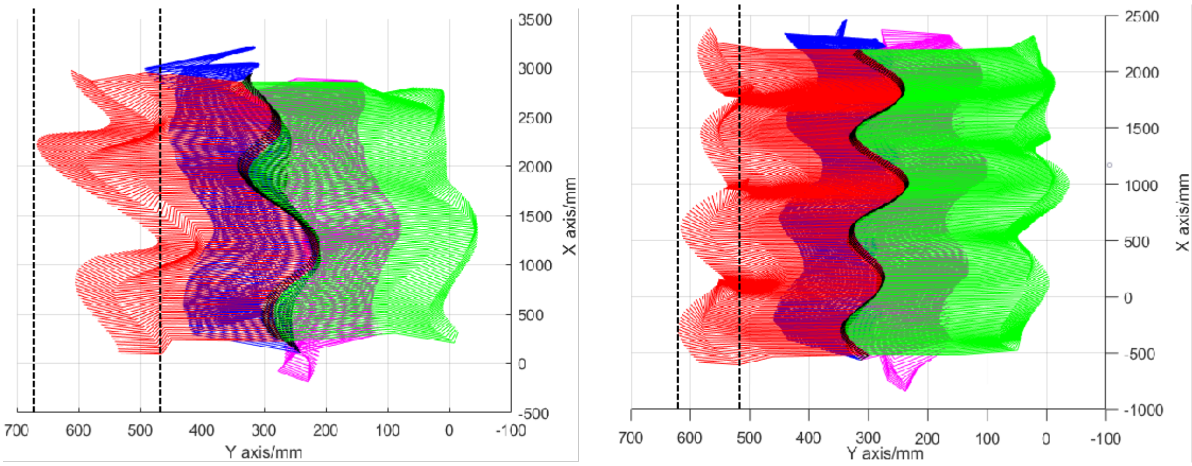
We use MATLAB to draw the walking state diagram of Tongsheng Li and Juan Zhao, so as to further compare their gait and walking posture. As shown in **Figure 7** .



(a) Tongsheng Li (b) Juan Zhao

Figure 7: Subject walking right view

In **Figure 7** are the superposition diagrams of the state of each frame of the subject during the test, in which the color of left and right hands and left and right legs are red and green, blue and pink respectively (in the figure, the subject walks to the right horizontal line). It can be observed from the figure that Zhao's foot lift height is around 0.2 m, while Li's foot lift height is higher than 0.2 m, even reaching 0.3 m at the maximum.



(a) Tongsheng Li (b) Juan Zhao

Figure 8: Subject walking top view

As can be seen from the top view **Figure 8**, Li's body has a large lateral swing, about 220mm. In contrast, Zhao's swing amplitude is smaller, which is within 100mm.

6.4 Suggestions

Combining the weight of each indicator with the actual data of the test takers ranked lower, we discover:

1. The top 5 indicators of weight ranking are pace S, lifting height H_L, limb movement angle $\Delta\theta_1$, $\Delta\theta_{10}$, $\Delta\theta_2$ and their corresponding weights are 0.277, 0.108, 0.066, 0.051, and 0.048, respectively.

2. For the test takers who ranked the bottom 10 in the WRSR value, the mean values of the five indicators mentioned in **1.** are 0.77m/s, 0.2m, 0.038°, 43.08°, and 1.132° respectively.

In summary, we give the following advice:

- Control the appropriate waking speed and try to adjust the pace at around 0.77m/s.
- Adjust the lifting height, which should not exceed 0.2m.
- Control body swinging amplitude, keep the head as far as possible shaking angle is about 1°, the swing angle of the leg should be controlled within 43.08°.

7 Balance Ability Assessment Based on Basic Data of the Elderly

7.1 Modeling Ideas

Due to the lack of relevant data in Annex 1, we are in the process of screening the basic indicators of the elderly, and scoring each tester according to the Elderly Fall Risk Assessment Scale, and then classifying each tester. Then we compare the classification results with the evaluation results in Model II, and combine the balance indicators and basic indicators of the elderly to give corresponding suggestions to those with poor balance ability.

7.2 Data Preprocessing and Selection of Basic Indicators

Based on the elderly patients' fall risk assessment scale, [13] we exclude the indicators with more data missing, and select the age, BMI, number of historical falls, number of illnesses, and whether the upper and lower stairs are by hand. We classify the indicators by studying the influence of each of them:

- People of different ages have different body balance abilities. Studies [14] have shown that as the age increases, the balance of the person's body will decrease.
- BMI is a neutral and reliable indicator to measure the fatness and health of the human body. The study on the effect of obesity on the dynamic balance ability of middle-aged and elderly people shows that the more the BMI value deviates from the normal range, the worse the balance ability of the elderly body. [15]
- The more the number of historical falls and the number of illnesses, the worse the body balance ability.
- The greater the degree of external force dependence, the worse the self-balancing ability.

Table 5: Elderly balance ability score sheet

Primary Indicator	Score	Secondary Indicators	Score
A-age	6	A1 $age < 65$	6
		A2 $65 \leqslant \text{age} < 75$	4
		A3 $75 \leqslant \text{age} < 85$	2
		$A4$ $age \geqslant 85$	0
B-BMI	6	B1 $\text{BMl} < 18.5$	4
		B2 $18.5 \leqslant \text{BMI} < 24$	6
		B3 $24 \leqslant \text{BMI} < 28$	4
		B4 $28 \leqslant \text{BMl} < 32$	2
		B5 $\text{BMI} \geqslant 32$	0
C-fall times	6	C1 $\text{time} = 0$	9
		C2 $\text{time} = 1$	6
		C3 $time \geqslant 2$	0
D-number of disease	6	D1 $\text{number} = 0$	6
		D2 $\text{number} = 1 \quad or \quad 2$	4
		D3 $\text{number} = 3 \quad or \quad 4$	2
		D4 $\text{number} > 5$	0
E- aid by hand or not	2	E1 no	2
		E2 yes	0

Indicators at all levels and scoring criteria are shown in **Table 5**.

The scale of this scale is 0–29 points. 0–14 is divided into poor balance ability, 15–19 is divided into balance ability general, 20–24 is divided into balance ability good, 25–29 is divided into balance ability excellent.

7.3 Actual Score and Analysis of the Balance Ability

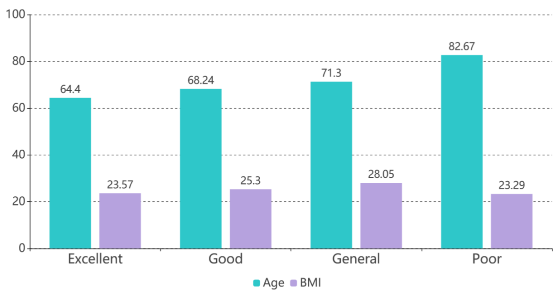
On the basis of **Table 5**, we can obtain the balance scores of each elderly people, as shown in **Table 6**.

According to the level of balance ability, we analyze the five indicators that affect the balance of the elderly, first analyze the different levels of the elderly, and replace the level with the mean. The results are shown in **Figure 9**:

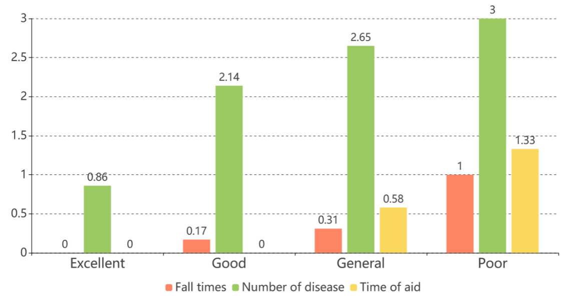
Combined with the figures above, we can draw the following conclusions:

Table 6: Balance Ability Scores of each Seniors

Name	Balance Ability Score	Name	Balance Ability Score
Jianshe Han	29	...	...
Zhenhua Cui	29	Yuling Gao	15
Jiuhong Wang	29	Yuhua Tong	15
Dafa Guo	27	Peihua Guan	12
Shengpu Jia	27	Yanfang Wen	11
...	...	Jinzhan Wu	11



(a) Age and BMI



(b) Fall Times, Disease and Aid Times

Figure 9: Intra-group Analysis for the Elderly with Different Grades

- The average age of the elderly with excellent balance ability is 64.4 years old, the average BMI value is 23.57, the average number of falls and the number of help needs are 0, and the average number of illnesses is 0.86, the average age of the elderly with poor balance ability is 82.67 years old, the average BMI value is 23.29, the average number of falls is 1 time, and the average number of helps needs was 1.33, with an average of 3 diseases.
- The level of falls of older people with different levels of balance ability is significantly different, and the level of illness is also significantly different.

7.4 Advice for Seniors with Poor Balance

Based on the comprehensive analysis of the risk assessment results and the balance scores of the elderly, we give the following suggestions for the elderly with poor balance ability:

- Seniors who over 70 years old have poor balance ability, so they should pay attention to adjust their walking posture and gait. When up and down stairs, they should hold the handrail or with the help of others.
- Elderly people with a BMO of more than 28 have poor balance ability. Therefore, they should reduce their intake of high-calorie foods so as to control their weight and blood pressure.

- The elderly suffering from a variety of diseases should take medicine in time, serious cases need to be accompanied care.

8 Testing the Model

8.1 Sensitivity Analysis for ω_i

In the process of constructing the evaluation system, the weight of each indicator directly affects the final evaluation result. The weights of the indicators determined by different methods are different.

We change the weights of the 25 indicators obtained by the entropy weight method by 5%, 10%, and 20%, and study the impact of changes in weights on the evaluation results. The ranking change rate obtained by the comprehensive evaluation of the rank-sum ratio is used as the weight of the influence. The results of each indicator are shown in **Figure 10**.

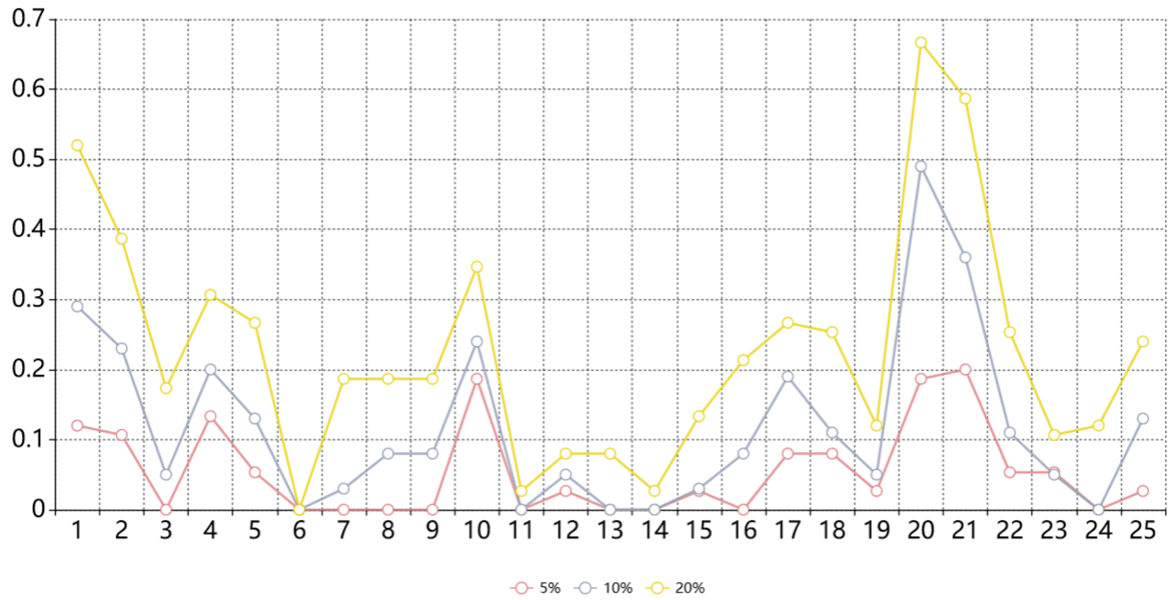


Figure 10: Influence of each Indicator on the Ranking at Different Levels

Analysis of the figure above shows that:

- The weight of each indicator has a great influence on the evaluation result. The weight of the indicator Cycle Time has a significant impact on the ranking result, while Right Arm Swing Angle scarcely has impact on the ranking result.
- The greater the change in weight, the more obvious the change in ranking results.

8.2 Conclusions

8.2.1 Strengths and Weaknesses

1.Strengths

- Our sensitivity analysis shows the extent to which the weight of each indicator affects the results.
- For Question I, 25 body balance indicators are specifically and numerically calculated from the abstract three-dimensional motion data, making the model universally applicable.
- In the elderly balance risk assessment system, the index weight extracted by the entropy weight method is very objective.

2.Weaknesses

- During the extraction process of body balance indicators, we use approximate values to replace the actual values for many times, and the obtained data may be biased.
- In the process of processing the data in Annex 2, due to the analysis limitations, many indicators are not considered.
- In the process of building the body balance score scale, the classification method is too subjective and relies on the score given by experts, so the result of body balance ability may be inconsistent with the reality.

8.2.2 Future Improvements

Since we still have some weaknesses in our current workfuture efforts are needed to better work out this problem.

First, when calculating each characteristic quantity of gait characteristics, we should carry out weighted average of gait characteristic quantity in each period, so as to be closer to the actual value.

Secondmore basic physical characteristics of the elderly need to be taken into account, in order to make a more comprehensive analysis and evaluation of the physical balance of the elderly.

Finally, we will try to generalize our model and apply it to study elder people's ability of balance when they are still or performing more complex movements.

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