Study on the Influence of Walking Speed on Human Upper Limb Movement Characteristics

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Abstract. Objective: To study the characteristics of the upper limb swing trajectory during different speed walking, and to analyze the different characteristics of the person walking at different speed, so as to provide a new way for the exclusion and identification of suspects or the control of important venues in criminal investigation. Methods: This paper measured and analyzed the angle of elbow joint and the amplitude of upper limb swing during walking of 10 healthy young men. Results: The general rule of the effect of walking speed on the elbow joint angle and the amplitude of upper limb swing was summarized. Conclusion: The change of walking speed during walking is related to the movement characteristics of upper limbs, and the left and right arm movements of the same person and the upper limb movement characteristics of different people are different.

1. Introduction
In this paper, by observing the changes of arm swing and elbow joint angle caused by upper limb movement during walking, the relationship between arm swing and walking speed was studied. This study explores the influence of the same person's upper limb swing amplitude and elbow joint space angle when walking at different speeds, and provides a new direction and basis for the study of the specificity of upper limb movement characteristics when walking. The research is based on biometrics technology, using the inherent biological characteristics of human body to carry out individual identity authentication, which has the remarkable characteristics of invariance and uniqueness. Combined with the three-dimensional motion capture system and SPSS data analysis software, through observing, measuring, calculating and analyzing the spatial trajectory of upper limb movement of the same person at different speeds, the influence of walking speed on upper limb movement characteristics is analyzed, and the universal law is obtained. [1]

In recent years, many people have done related research. Li Dianmei combines biometric technology to identify and judge human behavior in motion and distinguish individual identity in his article "Human Motion Feature Extraction of Video Image". She believes that people can drive hundreds of limbs to move synchronously during walking. These limbs of the human body contain a large amount of motion information, which is used to describe the dynamic characteristics of the human body and is easy to combine with other characteristics to identify personal identity [2]. Hongsheng Wang, Bai Xueling, Zhang Xi ‘an, Zhang Linlin and Wang Chengtao's article "Upper Limb Movement Simulation and Biomechanical Characteristics Analysis during Human Walking" has far-reaching significance in the fields of in-depth study of human upper limb movement status, research on human body movement
mechanism, and identification of individual identity through upper limb movement [3]. In the middle of
the last century, with MIT and Carnegie Mellon University as typical examples, a number of U.S.
colleges and universities participated in the research. The aim was to realize the analysis and
identification of pedestrian limb characteristics under non-contact and long-distance conditions, and
effectively improve the police's detection efficiency [4]. The major project ADVISOR set up by the
Framework5 Program Committee of the European Union IST aims to develop a system to effectively
manage the public transportation system, thus relieving the pressure of the city. It covers the analysis of
the behavior patterns of people and individuals, human-computer interaction and other research [5]. At
the same time, relevant scientific research institutions in Canada, Japan, South Korea, Switzerland and
other countries have also joined the research in this field. Intelligent video analysis technology has
developed rapidly under the promotion of the research results of these scientific research institutions [6].

In this paper, 10 subjects were selected to study the swing amplitude of upper limbs and the angle
between elbow joints when walking at different speeds. First of all, the same person walking at normal
speed was analyzed to observe whether the upper limb swing amplitude and elbow joint space included
angle were stable when walking at normal speed. Secondly, the same person walking at normal speed
was analyzed to observe whether the movements of the left and right arms were coordinated when
walking at normal speed. Third, the situation of the same person walking at different speeds is analyzed
to observe whether the upper limb movements of the same person walking at different speeds are
different.

2. Experimental Principle

2.1. Definition of Elbow Angle and Upper Limb Swing Amplitude

In this paper, the angle between the humerus of the upper arm and the ulna of the lower arm at the elbow
joint is defined as the angle between the elbow joint. Because the upper arm humerus and the lower arm
ulna are hard and difficult to deform, we may consider the upper arm and the lower arm as two rigid
bodies respectively. We can simply build a model: the small nodule at the intersection of the humerus
and scapula of the big arm is taken as a, the medial epicondyle of the humerus at the elbow joint is taken
as b, and the ulnar styloid process at the wrist joint is taken as c. Remember that the elbow angle is \( \angle ABC \).

In this topic, the distance between the two extreme positions reached by the big arm swinging back
and forth for one cycle when walking is called the upper arm swinging amplitude. Based on this model,
taking the right arm as an example, assuming that point A does not move, remember that the elbow joint
point is B1 when the big arm swings forward to the limit position, and B2 when the big arm swings
backward to the limit position. The larger |B1B2| is, the larger the swing arm amplitude is, and vice
versa. (The maximum swing amplitude of the left arm is recorded as |B1'B2'|)

Because of innate factors such as muscle, nerve and skeleton structure of human arm, the length of
arm, the flexibility of ligament and the coordination of walking are different, and the inconsistency of
acquired living environment and exercise leads to different walking habits. Because the upper limb
swing amplitude and elbow angle characteristics can reflect the walking habits of people, the individual
walking characteristics can be reflected by studying the upper limb swing amplitude and elbow angle
changes and angle peaks or valleys.

2.2. Measurement of elbow angle and upper limb swing using Vicon three-dimensional motion
analysis system

Vicon's three-dimensional motion analysis refers to the rapid recording of human movements by infrared
or other means, and the delayed analysis or repeated playback observation. By analyzing the captured
information, the changes of body kinematic parameters in a certain period of time are studied, and the
difficult-to-measure body kinematic parameters are studied.

Marker the ball on the left and right arms at points A, B and C respectively. The x, y, z coordinate
data of six marker spheres in the spatial coordinate system are derived in Vicon system software. The
three sides of the triangle formed by three points of each arm and the distance of elbow joint formed when the big arm swings back and forth to the limit are calculated. Finally, the included angle of elbow joint is calculated by using the inverse cosine function to analyze the change of upper limb movement.

2.3. Statistical analysis of stability of elbow angle and swing arm amplitude
In this paper, the variation index in statistical principle is used, that is, the index reflecting the degree of difference or dispersion of the mark values of each unit in the whole population. The specific formula is: C.V.=σ/μ, where σ is the standard deviation and μ is the average value. In general, the smaller the coefficient of variation, the smaller the degree of dispersion. In this paper, when studying the stability of elbow angle and swing arm amplitude variation, the coefficient of variation of elbow angle and swing arm amplitude is calculated to illustrate its stability.

2.4. Using SPSS data analysis principle to analyze the difference of upper limb movement characteristics
This paper uses T test in SPSS data analysis to explain the difference of upper limb movement characteristics. T-test will calculate a statistic T value, and SPSS will calculate sig value according to this T value. The sig value is generally compared with 0.05. If it is greater than 0.05, the average value is equal in probability greater than 5%. However, the probability is not equal to less than 95%, that is, the difference is not significant. If it is less than 0.05, the difference is significant.

3. Experimental Design

3.1. Experimental Material
In this study, Vicon 3D motion capture system is used to collect data. The system consists of 10 capture infrared cameras and acquisition software. The collection site is 6m×10m indoor, and its space can ensure the normal walking of the research object for more than two cycles. Set the acquisition frequency at 100Hz/s to ensure that there are no missing points and multiple points in the data acquisition process, and the accuracy and resolution during acquisition can meet the analysis requirements.

3.2. Experimental subjects
The subjects of this experiment are 10 healthy young men of the same age with different heights, body shapes and arm lengths.

3.3. Experimental process
The infrared camera should be corrected before the experiment. Firstly, the camera sensitivity threshold is adjusted so that the infrared camera can more accurately recognize the infrared light reflected by the marker ball and accurately read out the relative position of the space. Secondly, the sensitization range of the camera is calibrated; finally, the origin of the spatial coordinates is calibrated by modeling.

Points taken: The right humeral tubercle was taken as A, the medial epicondyle of humerus was taken as B, and the styloid process of ulna was taken as C. The small tubercle of humerus in the left arm is taken at A’, the medial epicondyle of humerus is taken at B’, and the styloid process of ulna is taken at C’.

Static modeling and static calibration: let the experimental object stand upright in the experimental area, keep both arms naturally drooping and still, press the calibration key to collect the relative positions of the three points, and then mark the names of the three points. Delineate the walking distance in the experimental area and mark the starting and ending points. Let the subject walk back and forth from the start point to the end point at different speeds until the speed stabilizes and start the Vicon 3D motion analysis system to record a complete video from the starting point to the end point. The walking time is measured, and the specific value of the walking speed is calculated (the speeds from v1 to v5 are slow to fast, distributed between 0.77 and 1.62 m/s), and each speed is tripped three times.
3.4. Collection and collation of experimental data

The marker sphere coordinate data of samples 1-10 are all derived and classified according to speed. For example, "sample 1 speed v3(1)" indicates the video data taken by the subject 1 walking at speed v3 for the first time. The data is the coordinate (x,y,z) data of 6 marker points recorded in excel.

Take the right arm as an example. In the table, note A (x1, y1, z1), B (x2, y2, z2), C (x3, y3, z3) to calculate the length of the sides AB, BC, AC of ΔABC. Respectively:

\[ |AB| = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \]
\[ |BC| = \sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2 + (z_2 - z_3)^2} \]
\[ |AC| = \sqrt{(x_1 - x_3)^2 + (y_1 - y_3)^2 + (z_1 - z_3)^2} \]

Then, \( \cos \angle ABC = \frac{AB^2 + BC^2 - AC^2}{2AB \times BC} \).

Then the ArcCOS function is used to find the angle of \( \angle ABC \), that is, the elbow angle when walking. Remember that the elbow joint point is B1(x4, y4, z4) when the big arm swings forward to the limit, and B2(x5, y5, z5) when the big arm swings backward to the limit. Calculate the distance between B1 and B2, i.e. swing arm amplitude, to obtain: \( |B_1B_2| = \sqrt{(x_4 - x_5)^2 + (y_4 - y_5)^2 + (z_4 - z_5)^2} \).

4. Analysis of Experimental Data

4.1. Analysis of stability of elbow joint angle and swing arm amplitude change when the same person walks at the same speed

4.1.1. Qualitative Analysis of Experimental Data

This part studies the stability of minimum elbow angle and maximum swing arm amplitude when the same person walks at normal speed. According to the right arm and left arm of Sample 1 to Sample 10, the spatial angle of elbow bending and the swing arm amplitude were calculated respectively during each video walk.

There are two parts to collect and analyze the change of elbow joint spatial angle when the same person walks at normal speed. Firstly, the change trend of left and right elbow joint angle was analyzed when 10 samples were walking at normal walking speed. Two groups of samples were randomly selected for analysis, labeled as sample 1 and sample 2, and the elbow angle was calculated. After that, the video frame number is taken as the X axis and the angle value is taken as the Y axis, and the corresponding line chart is made and named as elbow joint angle change chart.

The following are the data collected at the three points A, B and C for the first time when sample 1 and sample 2 walk at normal speed and the corresponding angle line chart:

The following is a line chart of elbow angle change when walking at normal speed as shown by comparing the above values (figs. 1 and 2):

Fig.1. Sample 1 right arm elbow joint angle
It can be seen from the image of sample 1 when walking at normal speed that the maximum angle of right arm elbow joint is more than 170, the minimum is less than 150, and the line is "steep"; The angle of the left arm elbow joint is basically kept between 160 and 170, and the line is relatively smooth. The change range of fold line reflects the stability degree of elbow angle change during walking, i.e. the steeper the fold line is, the more unstable it is, indicating that the greater the swing of the single-arm forearm during walking. When sample 1 walks at normal speed, the image shows that the angle change of the left arm elbow joint during walking is more stable than that of the right arm. It can be concluded that sample 1 walks with a larger swing of the right arm forearm and a stable swing of the left arm forearm.

Through further understanding of the situation reflected in sample 1, the reason why the right arm forearm swings more and the left arm elbow angle broken line image is smoother is that the subject is accustomed to writing, eating, lifting heavy objects with his right hand. The use of the right arm is more skilled than that of the left arm and the muscle strength is greater, so the swing force of the right arm is greater when walking. The subjects corresponding to sample 2 usually use their left hand to do some left-hand related movements such as lifting heavy objects, so their left arm is more powerful during normal walking, so their left arm has a large swing power during walking.

Studying the remaining samples has the same conclusion.

4.1.2. Quantitative Analysis of Experimental Data
The samples 1 and 2 were walked at normal speed three times. The left and right minimum elbow joint angles in each swing arm cycle were randomly selected and listed separately (as shown in Table 1), and the average and standard deviation of the left and right minimum elbow joint angle values were calculated. Coefficient of variation.

|                  | Minimum elbow angle of right arm | Minimum elbow angle of left arm |
|------------------|----------------------------------|---------------------------------|
| Average          | 156.03                           | 158.79                          |
| Standard deviation| 1.57                             | 1.62                            |
| Coefficient of variation | 0.01               | 0.01                           |

According to the data of the experimental samples in the table, the coefficient of variation of the minimum elbow angle of each sample is close to zero when walking. The results of the same analysis were the same for the other subjects. It can be seen that the elbow angle change is stable when people walk at the same speed.

The results of the same analysis were the same for the other subjects. The amplitude variation of swing arm is analyzed, and the stability is obtained.

4.1.3. Experimental conclusion
Since people have formed relatively stable muscle responses in the long-term use of arms, we can draw the following conclusions:
When the same person walks at normal speed, the amplitude variation of the left arm and the right arm single arm swing arms is stable. For example, when the same person walks at normal speed, when the left hand is the dominant hand, the left arm has a greater swing force than the right arm, and the angle of the left arm elbow joint changes greatly. When the right hand is the dominant hand, the left arm has less swing force than the right arm when walking, and the angle change of the left arm elbow joint is stable.

4.2. Study on the Difference of Motion Change Characteristics of the Left and Right Arms of the Same Person in Normal Speed Walking

4.2.1. Study on the Difference of Elbow Angle
This part uses qualitative description method to study the difference of elbow angle changes of the left arm and right arm when the same person walks at normal speed. Since the stability of upper limb movement characteristics during walking has been studied above, only the first walking data of each sample need to be studied in this part of the study. Two samples were randomly selected and recorded as sample 1 and sample 2. Taking speed v3 (walking at normal speed) as an example, the first data change trend of left and right arms was observed and angle line charts (as shown in figs. 3 and 4) were made.

![Fig. 3. Sample 1 elbow joint angle change](image1)

![Fig. 4. Sample 2 elbow joint angle change](image2)

The above is a line chart showing the elbow angle of normal speed walking in samples 1 and 2. It can be seen that the images of the left and right arms of the same person are not completely the same, which indicates that the angle changes of the elbow joints of the left and right arms are different when the same person walks. Using the same method, qualitative analysis was carried out on the remaining 8 sample data, and the results were the same. It can be seen that there are certain differences in the angle changes of left and right elbow joints when walking in the same person.

4.2.2. Research on Difference of Swing Arm Amplitude
This part uses quantitative description method to study the difference of swing arm amplitude between Left arm and Right arm when the same person walks at normal speed. Similarly, taking the first-time walking data as an example, the functional relationships are respectively established for each sample with speed as independent variable x and swing arm amplitude as dependent variable y.
In order to facilitate the analysis of data, x is made into a table by taking specific five different values (for example, table 2, the corresponding value of y is kept two decimal places):

Table 2 Sample 1, 2 speed x value and swing arm amplitude y corresponding value data (swing arm amplitude unit: cm)

|       | 0.7  | 1.0  | 1.3  | 1.6  | 1.9  |
|-------|------|------|------|------|------|
| Sample 1 | Right arm | 28.69 | 31.02 | 33.34 | 35.66 | 37.99 |
|        | Left arm  | 27.63 | 30.12 | 32.61 | 35.10 | 37.58 |
| Sample 2 | Right arm | 27.37 | 29.67 | 31.96 | 34.25 | 36.55 |
|        | Left arm  | 28.34 | 30.81 | 33.27 | 35.74 | 38.21 |

Observing the above table data, it can be seen that regardless of the value of x, the values of the left and right arm of the same sample are different. Each person's left and right arm swing arm amplitudes will form different linear functions with the change of speed. This can explain the difference in the amplitude of the left and right arm swing arms when the same person walks.

4.2.3. Experimental Conclusion

Due to the length of the arm, the strength of muscles and ligaments, and the conventional arm, the swing force of the left Right arm is different when the sample walks, and the included angle and swing arm amplitude of the left Right arm elbow joint are also different. After analysis, two conclusions can be drawn:

When the same person walks at normal speed, the angle change of left and Right arm elbow joints and the swing arm amplitude are different.

4.3. Study on the Difference of Movement Variation Characteristics of the Same Side Arm when the Same Person Walks at Different Speed

(1) Study on the Difference of Elbow Angle

This part studies the difference of angle change of Right arm elbow joint when the same person walks at different speeds.

First, the qualitative description method is used to illustrate the difference of angle change of Right arm elbow joint when the same person walks at different speeds. Two samples are randomly selected and recorded as sample 1 and sample 2. Observe the walking data change trend of Right arm when the two samples walk for the first time at the speeds v2, v3 and v4, and make elbow angle line charts (as shown in Figs. 5 and 6):

Fig. 5. Sample 1 right arm elbow joint angle change
Fig. 6. Sample 2 right arm elbow joint angle change

It can be seen from the above line drawing that the angle image of the angle of the elbow joint of the same person is not exactly the same when walking at different speeds, which means that there is a certain difference in the angle of the elbow joint of the same person when walking at different speeds. The remaining 8 sample data were analyzed and the results were the same. It can be seen that the angle of the elbow joint of the Right Arm is different when the same person walks at different speeds.

Secondly, the quantitative description method is used to illustrate the difference in the angle of the elbow joint of the same person when walking at different speeds. Two samples were randomly selected and recorded as sample 1, sample 2. The stable minimum elbow joint angles at v1, v2, v3, v4, and v5 were processed by T test method. The results are shown in Table 3:

| Sample 1  | t   | df | Sig. (Bilateral) | Mean difference | 95% confidence interval of difference | Lower limit | Upper limit |
|-----------|-----|----|------------------|-----------------|--------------------------------------|-------------|-------------|
|           | 30.985 | 4  | .000             | 147.35800       | 134.1537 - 160.5623                   |             |             |
| Sample 2  | 46.369 | 4  | .000             | 149.48600       | 140.5352 - 158.4368                   |             |             |

Observing the data in the above table, the Sig values of sample 1 and sample 2 are all less than 0.05, and the difference of Right arm stable minimum elbow angle between sample 1 and sample 2 at five different speeds is significant. Therefore, it can be explained that the angle change of right arm elbow joint is different when the same person walks at different speeds.

(2) Research on the Difference of Swing Arm Amplitude

This part studies the difference of swing arm amplitude of Right arm when the same person walks at different speeds.

The quantitative description method is used to illustrate that the swing arm amplitude of Right arm is different when different people walk at normal speed. Two samples are randomly selected and recorded as sample 1 and sample 2. Observe the walking data of Right arm when the two samples walk for the first time at the speeds v1, v2, v3, v4 and v5, and process the data using T-test method. The results are shown in Table 4:

| Sample 1  | t   | df | Sig. (Bilateral) | Mean difference | 95% confidence interval of difference | Lower limit | Upper limit |
|-----------|-----|----|------------------|-----------------|--------------------------------------|-------------|-------------|
|           | 30.196 | 4  | .000             | 31.69600        | 28.7816 - 34.6104                    |             |             |
| Sample 2  | 29.484 | 4  | .000             | 30.61400        | 27.7311 - 33.4969                    |             |             |
According to the data in the above table, the Sig values of sample 1 and sample 2 are all less than 0.05, and the amplitude of Right arm swing arm of sample 1 and sample 2 are significantly different at five different speeds. This shows that the amplitude of the Right arm swing arm is different when the same person walks at different speeds.

Research on Left arm related data shows the same conclusion. That is, when the same person walks at different speeds, the minimum elbow angle and swing arm amplitude of Left arm are different.

5. Conclusion
According to the design, 10 subjects were randomly selected for experimental research, and walking speed was divided into five different speeds, so that each subject walked 10 times at each speed for video shooting. Then, according to the captured video, the motion coordinate data of joint points are derived and a table is made, and data analysis and correlation research are carried out. The conclusion is summarized as follows:

1. For the same person walking at normal speed, the left and Right arm elbow angle changes and swing arm amplitude have stability.
2. For the same person walking at normal speed, the swing force of the conventional arm is large, and the angle of elbow joint changes greatly.
3. For the same person walking at normal speed, there are differences in left and right elbow angle changes and swing arm amplitude.
4. The faster the same person walks, the greater the swing force of the arm and the smaller the elbow angle. On the contrary, the slower the walking speed, the smaller the swing force of the arm and the larger the elbow angle. The faster the same person walks, the greater the swing of his upper limbs. On the contrary, the slower the walking speed, the smaller the swing amplitude of upper limbs.

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