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Research of Digital Characteristics of the Step Cycle in Forensic Medicine

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Abstract: This article presents the results of a study devoted to the analysis of the characteristics of the human step cycle as an indicator that allows you to identify a person on video by the signs of gait. Video recordings of volunteers walking on an electric treadmill were used as the research material. A software package has been developed that allows calculating the parameters of the step cycle used for processing the material. The average values of such characteristics of the step cycle were obtained and analyzed, such as the duration of the transition period and double support as a percentage of the step cycle and seconds, the length of the step cycle in seconds, walking frequency, walking pace separately for men, women and for the entire sample as a whole. The change of the listed indicators depending on the walking speed is investigated, the change in the frequency of steps with increasing speed is analyzed. A method of identifying a person in a video based on the characteristics of a step cycle is proposed, which allows comparing the digital characteristics of steps and making a reasonable conclusion about their similarity or difference. A software package has been developed to determine the anthropometric parameters of an individual in a video based on the characteristics of the step cycle. The obtained results can be used in forensic medicine for conducting expertise on identification of a person by signs of gait.

Keywords*:* Characteristics of the step cycle, gait signs, identity identification, analysis of video materials.

1. Introduction

The modern level of development of information technologies and technical means contributes to improving the effectiveness of measures to investigate and solve crimes [1-3].

Video surveillance systems are one of the tools that help law enforcement agencies in investigating crimes [4-5]. They allow to record information that is later used in investigative measures [6-8].

In the case then a person's face is clearly fixed on the video, or any special signs are visible, the task of portrait identification of a person does not cause difficulties. Nevertheless, expertise in which a person's face is not visible on the video (since it is hidden by a mask, or the shooting was made at an unsuccessful angle) are relevant [9-10].

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When working with such video material, the only sign that characterizes the individual in the video is the gait. Gait has a large complex of dynamic characteristics. However, there is a problem in choosing such a set of significant signs that are clearly recorded regardless of the shooting angle.

Recently, interest in the problem of identifying a person in a video by signs of gait has especially grown. The proposed methods are based on the analysis of human movement characteristics but use different tools.

The first group of techniques is based on the use of neural networks. Their essence lies in recording the primary signs of gait and transmitting them to the input of a neural network, which, by processing the data, generates a signal about the identity or difference of individuals. The difference lies in the set of input information and network architecture. For example, in articles [11, 12], the input information was blocks of optical flow maps. In article [13], the neural network was trained based on data from binary silhouette masks. In research [14], the source of primary information is a three-channel image, including black and white frames and components of optical flow maps.

The second group of methods uses the analysis of basic gait signs, for example, such as gait energy [15-17], the position of joints and main parts of the body [18, 19], and the trajectory of movement of figure points during walking [20].

Each method has its own implementation signs. Methods based on the use of neural networks are characterized by high computational costs, and for methods based on the analysis of basic signs, difficulties are associated with the analysis of video material from an unsuccessful angle.

Thus, due to the large number of conditions affecting the manner of human movement and its presentation in video, the problem of identification by gait still does not have a sufficiently accurate solution.

In forensic medicine, the urgent task is to study the signs of gait and developing methods that allow for a comparative analysis of the gait signs of several individuals presented in different videos and to draw a conclusion about their similarities or differences, as well as to form informed expert opinions that can be presented as an evidence base.

In this work, we study such a dynamic gait sign as the step cycle.

The purpose of this research is to study the digital characteristics of the step cycle as one of the parameters that allow identification of a person by the signs of gait.

2. Collection and Processing of Materials for the Organization of Research

2.1. Research Materials

The step cycle is the time from the beginning of contact with the support of a fixed leg to the next contact with the support of the same leg. The step cycle includes two periods that are repeated twice - the period of double support, when both legs are in contact with the support, and the transfer period (or the period of single support) [21] (Figure 1).

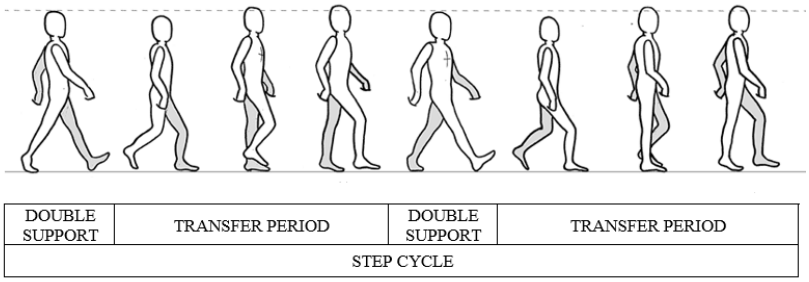

Figure 1. Step cycle.

To analyze the characteristics of the step cycle, video recordings of walking were analyzed. On the video recordings the volunteers walked on an electric treadmill with a speed of 3 to 7 km/h.

The shooting time was 20-30 seconds for each speed mode. During this period, the volunteer took 7-10 steps of natural walking without bending his torso and touching his hands with the handrails or the scoreboard of the track, stabilizing his movement. A prerequisite for fixation was a complete hit in the shot of the track platform and the legs of the subject, as well as a clear visualization of the contact with the platform of both feet.

Each video was supplemented with accompanying information, including the gender, age, height and body weight of the individual. The frame rate was recorded for each recording. The resulting videos corresponding to different speed modes were decomposed into a video sequence. A cyclogram corresponding to four consecutive steps was extracted from each video sequence to identify the characteristics of an individual's walking with support on the left and right legs. Cyclograms were loaded into the «Software package for calculating the characteristics of the step cycle» [22], designed to calculate the parameters of the step cycle.

2.2. Research Method

A software package was developed to calculate the characteristics of the step cycle. The software package includes the following modules:

1. Module for entering source information into a database (examination number, date, gender, height, body weight, age, number of frames per second, distinctive signs).

2. Module for calculating the characteristics of the step cycle. When working with the module, the expert loads frames on which the full cycle of the step is recorded. Next, the frame numbers corresponding to the beginning and end of each period are recorded. Fixation begins either with a period of double support, or with a period of transfer. When fixing, a record is made of which leg (left or right) the cycle in question begins. In automatic mode, the calculation of such indicators of the step cycle as:

- the length of the first and second periods of the double support in seconds and percentages of the step cycle;
- the length of the first and second transfer periods in seconds and percentages of the step cycle;
- step cycle length in seconds;
- walking frequency;
- walking pace.

As a result of the processing of video recordings, a «Database of human step cycle characteristics» was formed [23], containing information about the digital characteristics of the steps 129 individuals aged 16 to 60 years.

The processing of four steps was carried out in order to identify the individual characteristics of the subject's walking with support on the left and right legs, as well as in order to obtain stable results.

3. Analysis of Research Results

3.1. Checking the Reproducibility of the Results

At the first stage of the analysis of the results, their reproducibility was checked. The same videos were processed by different experts, then measurements were compared. The discrepancy in the data obtained by different experts was no more than 1%, which indicates good reproducibility and the possibility of using the digitization algorithm and the software package both to study the numerical characteristics of the step cycle and to solve the identification problem.

For further data analysis, the step cycle indicators for four steps were averaged at each speed mode for each individual.

The study of the results was carried out in the following areas:

- study of the digital characteristics of the step cycle as a parameter that allows for identification of an individual.
- analysis of the general regularities of the characteristics of the step cycle.

3.2. Descriptive statistics

The second stage of the study is the calculation of descriptive statistics for each speed mode. This article presents the results for a speed limit of 5 km/h, which corresponds to the natural pace of walking. The length of each double support period averages about 14.3% of the step cycle, and the length of each transfer period averages 35.5%. The total time of double support per step cycle is on average 29%, and the transfer time is 71% of the step cycle, which corresponds to 0.29 seconds and 0.73 seconds, respectively.

According to the data obtained, the average duration of the step cycle when walking at a speed of 5 km / h is 1.03 seconds, the average walking frequency is 116.4 steps per minute.

The above indicators were separately analyzed for men and women. The result is presented in Table 1.

Table 1. Characteristics of the step cycle at a walking speed of 5 km/h for men and women

Characteristic	Men	Women
Average duration of the double support period:		
in % of the step cycle	15,00	14,00
in seconds	0,16	0,14
Average duration of the transfer period:		
in % of the step cycle	34,80	35,9
in seconds	0,37	0,38
Average duration of the step cycle, in seconds	1,06	1,04
Average walking frequency, steps per minute	111,08	118,36

Men are characterized by longer periods of double support and shorter periods of transfer than women. Also, the average duration of the step cycle in men is longer than in women, and women are characterized by a high frequency of walking.

For a more detailed analysis, the Student's t-test was calculated in the difference between the average values for men and women and it was found that the differences in the average values are statistically significant for all indicators of the step cycle at each speed mode. Table 2 shows the indicators for the speed of 5 km/h.

Table 2. P-values for the Student's t-test

Indicator	t-value	p-value
The first period of double support (sec)	-4,48	0,000016
First transfer period (sec)	-2,37	0,021419
Second period of double support (sec)	-5,05	0,000001
Second transfer period (sec)	-2,17	0,031419
First period of double support (%)	-2,75	0,006819
First transfer period (%)	4,19	0,000051
Second period of double support (%)	-3,67	0,000348
Second transfer period (%)	2,40	0,017588
Average duration of the step cycle, in seconds	-4,47	0,000017
Average walking frequency, steps per minute	4,32	0,000031

Using data from the numerical characteristics of the step cycle and the anthropometric parameters of individuals, a software package was developed to determine the height, weight and gender of a person captured on video footage [24].

The software package is based on the Random Foresrt algorithm, which is a machine learning method that involves using an ensemble of trees to solve regression, classification and clustering problems. The Random Forest algorithm allows us to mitigate the problem of overfitting, generate a fairly stable solution, and increase classification accuracy. Another important advantage of the algorithm is the ability to evaluate the measure of information content of each variable.

The algorithm made it possible to determine the most informative signs, i.e. signs that are most important for prediction: values of the periods of transfer and support as a percentage of the step cycle.

Below is an example of how classification algorithms work for a specific expert case. As a result of the analysis of the characteristics of the step cycle, the expert recorded the following average values of indicators (Table 3).

Table 3. Input data

№	Sign	Value in % of the step cycle	Value in seconds
1.	Duration of the first period of double support	16,89	0,22
2.	Duration of the second period of double support	17,63	0,23
3.	Duration of the first transfer period	32,64	0,43
4.	Duration of the second transfer period	32,83	0,43
5.	The duration of the step cycle in seconds	1,3	
6.	Number of steps per minute	90,10	

The presented information was uploaded as input data to the software package [24]. As a result of data processing, the following results were obtained (Table 4).

Table 4. Input data

Parameter	Height	Weight	Gender
Predicted value (Random Forest)	164,7	62	2
Real value	162	58	2

The developed software package can be used to determine the anthropometric parameters of a person on a video recording during a forensic medical examination if there are no objects on the video whose dimensions are known.

3.3. The study of Indicators in Dynamics

The study of the indicators of the step cycle in dynamics showed that with an increase in walking speed, there is a decrease in the duration of the periods of support and transfer in seconds. For the same indicators, as a percentage, there is a decrease in the period of double support as a percentage of the step cycle and an increase in the duration of the transfer period as a percentage of the step cycle.

The length of the step cycle also decreases with increasing speed, and the step frequency increases (Table 5, Figure 2-5).

Table 5. Average indicators of the step cycle in dynamics

Speed	Double support period		Transfer period		Step cycle	Step frequency
	sec	%	sec	%		
3 km/h	0,25	18,71	0,41	31,29	1,32	91,70
4 km/h	0,20	16,88	0,39	33,12	1,18	102,46
5 km/h	0,15	14,35	0,37	35,64	1,04	116,49
6 km/h	0,13	12,98	0,36	37,02	0,97	124,00
7 km/h	0,13	12,87	0,35	37,13	0,95	128,49

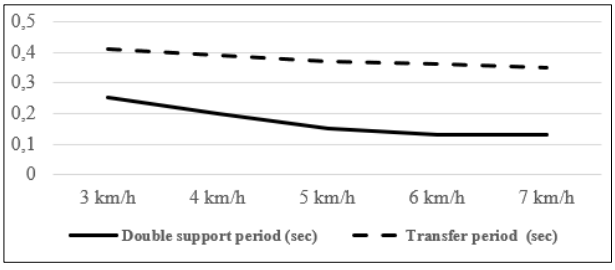

Figure 2. The lengths of periods in %.

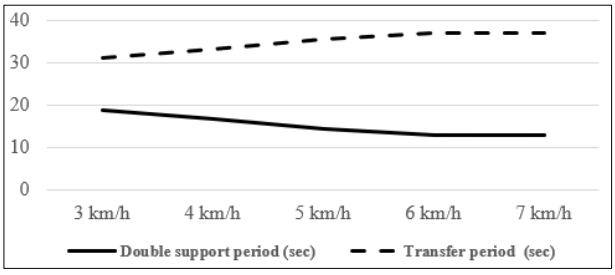

Figure 3. The lengths of periods in sec.

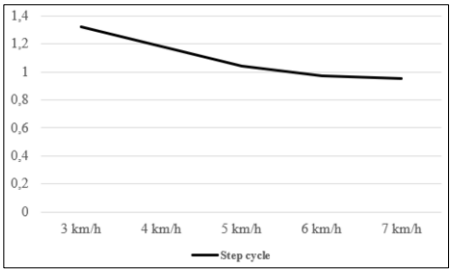

Figure 4. Step cycle length.

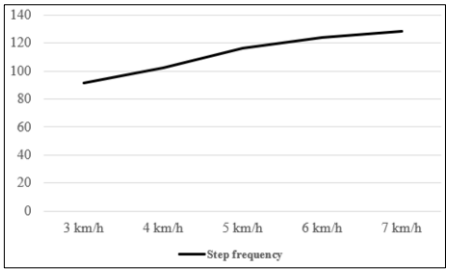

Figure 5. Walking frequency.

Having data on the relationship between the characteristics of the step cycle and the walking speed, it is possible to compare, comparative research and further examination of the identification of individuals when they move at different speeds on video footage.

3.4. Study the Characteristics of Walking

Studying the signs of the step cycle allows us to conclude that individuals can be divided into groups:

- depending on the characteristics of the single support period:

1) individuals whose period of single support on the left leg is longer than the period of single support on the right leg;

2) individuals whose period of single support on the right leg is longer than the period of single support on the left leg;

3) individuals whose periods of single support on the left and right leg are the same (about 5% of cases in the sample);

- depending on the characteristics of the double support period:

1) individuals who have a longer period of double support before the transfer of the left leg;

2) individuals who have a longer period of double support before transferring the right leg;

3) individuals whose periods of double support are the same (about 9% of cases in the sample).

It is established that the "symmetry" of the periods is preserved with a change in velocity. This feature makes it possible to compare the durations of periods when moving at different speeds.

The obtained results allow us to propose an identification algorithm based on the characteristics of the step cycle, which may consist of the following stages:

identification of rare walking signs that are not characteristic of the bulk of individuals (lameness, special foot position when supporting, etc.);

decomposition of a video recording into a video sequence and selection of four consecutive steps from a cyclogram;

digitization of the step cycle;

comparative analysis of the periods of the step cycle, assessment of the «symmetry» of periods, classification of individuals depending on belonging to a particular group;

calculation of anthropometric parameters.

As a result, an expert opinion on the comparative analysis can be formed.

An example of an expert opinion comparing the digital characteristics of the steps of three individuals is presented in Table 6.

Table 6. Expert opinion

Video	First transfer period Support on the left leg, transfer of the right leg	The first period of double support The period of support before the transfer of the left leg	Second transfer period Support on the right leg, transfer of the left leg	Second period of double support The period of support before the transfer of the right leg	Average duration of the step cycle (sec)	Average walking frequency (steps per minute)
1	0,36 sec	0,14 sec	0,35 sec	0,12 sec	0,97	123
	37,01 %	14,37 %	36,01 %	12,60 %		
	0,36 sec> 0,35 sec		37,01 % > 36,01 %			
	0,14 sec> 0,12 sec		14,37 %> 12,60 %			
2	0,36 sec	0,16 sec	0,38 sec	0,15 sec	1,05	114
	34,50 %	15,25 %	36,40 %	13,87 %		
	0,36 sec < 0,38 sec		34,50 %< 36,40 %			
	0,16 sec > 0,15 sec		15,25 %> 13,87 %			

Prediction of height, weight, and gender based on the characteristics of the step cycle:
video №1 - height 170 cm, weight 84 kg, and female gender;
video №2 - height 165 cm, weight 80 kg, and female gender.

Conclusion: the individual shown in video No. 1 is characterized by a longer period of single support on the left leg unlike the individual in video No. 2; the individual in video No. 2 has a longer average duration of the step cycle and a lower average walking frequency. It can be concluded that the digital characteristics of the steps of individuals in video No. 1 and No. 2 are different.

4. Conclusions

The article describes the results of a study devoted to the analysis of the characteristics of the step cycle, as one of the gait parameters, allowing comparison of individuals in video footage.

A collection of materials was made, representing video recordings of the volunteers walking on an electric treadmill. A «Software package for calculating the characteristics of the step cycle» has been developed, which made it possible to digitize information. As a result of the processing of video materials, a «Database of human step cycle characteristics» was formed, which is a material for statistical analysis.

The analysis of the periods of the step cycle is carried out and an algorithm for identifying an individual by his characteristics is proposed.

The analysis of the indicators of descriptive statistics of the characteristics of the step cycle was carried out, a statistically significant difference was found in the average values of the periods of support and transfer (in seconds and percentages of the step cycle) for men and women: men are characterized by longer periods of double support and

shorter periods of transfer than for women, a longer average duration of the step cycle and a lower frequency walking.

The analysis of indicators in dynamics (i.e., with a change in walking speed) is carried out: with an increase in walking speed, the lengths of the first and second periods of double support in seconds, as well as the first and second periods of transfer in seconds, the length of the step cycle decrease, which simultaneously leads to an increase in the frequency of the step.

An algorithm has been proposed and a software package has been developed to determine the anthropometric parameters of a person in a video.

The developed software systems can be used for diagnostics during forensic and forensic examinations, as well as in investigative activities.

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