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REVIEW

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Gait analysis techniques

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Abstract This paper reviews the main techniques developed for gait analysis, which are categorized according to the type of analysis they perform. Their main positive and negative aspects are presented. These aspects, together with the experience, technical support and innovation of each gait laboratory, are essential for the choice of a technique for a lab.

Key words Gait analysis · Kinematics · Kinetics · Spatiotemporal parameters

Introduction

Gait analysis is applied in the assessment of human gait and the accumulation of data that describes and characterizes it. Gait analysis helps distinguish between normal and pathological gait, estimate the course of an orthopedic problem, and assess the need for prosthetic and orthotic devices for the upper and lower limbs.

Several techniques have been developed for gait studies. They differ in the type of information they offer, as well as in their methodology. Some of them are more applicable in a research laboratory, but less appropriate for routine clinical practice, and offer much information regarding human gait. All the same, they are expensive, need strong scientific and technical support, and are in most cases time-consuming in their preparation and use [1, 2]. On the other hand, some other techniques are applicable in routine clinical practice, are inexpensive to build and run, and do not require specifically trained personnel for their function and maintenance. Although the amount of information they offer is less than that of more composed techniques, they are still valuable [3–6].

This paper reviews the types of techniques developed for gait analysis and presents their main aspects.

Categories of gait analysis techniques

The techniques developed for gait analysis are divided into those that:

1. Record footfall timing, and the displacement of the foot during contact with the ground,
2. Perform pinematic analysis, permitting assessment of the movement of parts of the human body - or the human body as a whole,

3. Perform kinetic analysis, permitting evaluation of the applied forces to the foot during stance phase, the forces and torques between segments of the human body, the muscle and joint forces, the energy produced by the body muscles, and in general whatever is relevant to the dynamics of the body during gait.

Techniques that assess footfall timing and displacement of the foot during contact with the ground

Assessment of footfall timing

In several of these techniques, the assessment of footfall timing is achieved with the use of sensors of different types. Some sensors are made of springs connected to bush-buttons or of electronic material that becomes active under the influence of a magnetic field [7]. Others can be made of piezoelectric transducers that consist of polymer film that lies between two strips of tin [5], or of conductive material with variable resistance, whose value changes under load [8].

The sensors are either placed insole under certain parts of the foot, such as the metatarsals, the heel, the arch, and the toe, or under the subjects' shoes. In this way, the gait cycle duration, the single and double support durations for both feet, as well as the contact times for certain parts of the sole are assessed.

Most of the techniques that utilize sensors are inexpensive and easy to build, do not require high technical support, and can be used in routine clinical practice. All the same, the subjects' gait is often affected or hindered by the sensors' volume or by the heavy wiring required by the composed electronic layouts. Special soles have to be built in some cases for the sensors' placement. Problems of mechanical endurance may also occur.

Footfall timing can also be assessed with the use of walkway systems [9] or conductive walkways, which may vary in length and thickness and can be made of any metallic material. Either the walkway strips are connected to a computer [9], or the strips that are glued under the subjects' shoes are connected to a circuit of resistances of different values [6, 10, 11], or to a telemetry system that is furthermore connected to a recorder or computer [3, 12, 13]. The subjects are asked to perform their passes using slow, normal or fast speed. The mean speed of progression is assessed via photocells, or by the time required by the subjects to transverse a known distance.

The techniques that utilize walkways are inexpensive, can be used in routine clinical practice, do not require high technical support, are easily reproducible, and in most cases do not impose heavy wiring on the examined subjects.

Portable recorders have also been designed for the assessment of the temporal phases of gait. The recorders can be connected to footswitches [14], accelerometers [15], or conductive polymer sensors placed insole [16, 17]. The recorders are connected to computers after the subjects' runs for further processing of the gait signals. Their main positive aspects are their light weight and portability; all the same, due to their high costs, these instruments are not always affordable.

Computation of both times and displacements of the foot during contact time

Several systems have been developed for the assessment of not only the temporal, but also the spatial parameters of gait, i.e. the stride length, the width of gait, and the angle of the feet during gait. A simple way to do that is by placing a paper on a walkway, where the footmarks can be seen. This method is inexpensive, but consumes time in the data processing and has questionable accuracy.

Other more sophisticated, low-cost techniques have been developed, most of which use sensing elements placed perpendicularly to a walkway. The use of multiplexers, which are furthermore connected to a computer, gives addresses to every sensor. In this way, one can see on the monitor the address and the time during which each sensor is closed [4, 18–22]. Due to the large number of sensors and the complexity of the electronic layouts, most of these techniques are not easily reproducible.

The newest, commercial techniques utilize portable sensing walkways that are connected to laptop computers [23]. Although they are extremely functional, easy-to-use and portable, their cost is prohibitive to research laboratories with restricted financial support.

Techniques for kinematic gait analysis

Goniometry

The recording of the movement of at least one of the body parts is much more complicated than the study of foot-floor contact. The simplest of all is the case in which the angle between two segments of the human body (e.g. thigh and tibia) is to be studied. Goniometry is an aspect of motion analysis, which attempts to quantify the range of movement of a joint (or joints).

A variety of methods and instruments, in most cases inexpensive, exist for the accumulation of goniometric data. Some of these are self-constructions (e.g. potentiometers that produce electrical signals with magnitude analog to the angle of displacement [24]; other devices, as the electrogoniometers, offer a high degree of accuracy, the possibility of dynamic measurement, and are independent of joint center [25–29].

Other types of goniometers, such as the universal (manual) or the fluid goniometer, have also been used by researchers for motion analysis [30–32]. The universal goniometer is simple to use, noninvasive, and provides data that are a valid measure of joint range of movement [33]. However, there are movements that are not amenable to measurement by it. On the other hand, the fluid goniometer is small, allows speed of application and operates independently of the axis of joint rotation.

Cameras

The techniques that utilize cameras record the movement of various parts of the human body (or of the body as a whole). The displacements of joints are assessed via image analysis. These techniques can be categorized as follows:

Systems of cinematography cameras. Markers are placed on special parts of the subjects' bodies, who then walk in a room with 2 or more cameras. The cameras are placed in such a way, so that each marker is visible by at least two of them. If the markers are reflective, no light is required in the room where the passes take place; in any other case, the room must be highly illuminated. A system of coordinates is simultaneously recorded with the help of reference markers.

So as to achieve accurate results, the *parallax error*, which occurs due to the recording of a marker position at only one plane and the *camera turn error*, which occurs due to possible movement of the camera off its initial position, have to be corrected. Sampling rate is 50 frames/s or more. The film is analyzed and the markers' initial positions are recorded. From the positions of the same marker viewed by at least two cameras, its real coordinates for each frame are computed. In this way, the positions and angular displacements of according parts of the body are assessed.

The cinematography technique has been reported not only for gait analysis [34–37], but also for other biomechanics studies [38]. It is quite accurate and offers much information regarding human movement. All the same, even with the use of digitizing techniques, the film analysis is time-consuming.

Systems of video cameras. The principle of function in videography is similar to that of cinematography.

The cameras' sampling rate can be 50, 100 or 200 frames/s. The cameras' outputs are inputted to a computer, where appropriate software processes the recorded data and presents results [39–44].

Videography for gait analysis is not time-consuming regarding data processing; moreover, it is rich in information concerning human gait. All the same, its preparation and use are time-consuming, the equipment cost is high, and specifically trained personnel are required for its function.

Other motion analysis systems. No other gait analysis technique offers the amount of information that the following three motion analysis techniques offer. However, a disadvantage of these three systems is that the examined subjects are obliged to walk almost naked, and in most cases in rooms where there is little light.

- *Systems based on photosensitive two-dimensional semiconductors for position determination.* These are photosensitive semiconductors, with which the cameras are equipped; the light produced from reflective markers, which are placed on the subjects' bodies, ignites them. For each frame, two electrical signals that correspond to the markers' position in each plane are produced. These signals are then inputted to a computer and processed [45]. A disadvantage of such a system is that only one marker can be recorded at a time. This is why markers that produce successive infrared beams are used. The cost is similar to that of a videography system.
- *Systems based on one-dimensional lines of sensors.* These systems use lenses that focus the signal from a marker perpendicular to a series of photosensitive sensors. Two series of sensors of this sort form a two-dimensional recording camera. At least two cameras of this sort are required for the computation of the three-dimensional position of a marker [45]. A negative aspect of such a system is the high cost and heavy wiring of the subjects.
- *Systems based on optical sweepers.* The markers used in such systems are made of glass with various colors. Three beams of light are used for the computation of the coordinates of the moving parts of the human body. These beams are reflected by the glass markers and are sensed in the source of light transmission. The angles of reflection are used for the computation of the three-dimensional position of the markers [45].

Techniques for kinetic gait analysis

Force plates

There is no direct way to assess the forces developed between bones, nor the forces developed by muscles during gait. One has first to assess the external forces that are applied to the human body, i.e. the force of human weight, as much as the floor reaction force during stance phase. These forces are assessed with the use of relatively inexpensive systems developed in research laboratories for dynamic analysis [46, 47] using commercial force plates, which compute the vertical and horizontal components of the applied forces, as well as the points of application during foot-floor contact. Two of them are usually required, one for each foot.

A system that consists of two force plates and the necessary electronic layout is expensive to buy and requires specialized technical support. All the same, such a technique does not require long preparation time for its use. There is the ability for measurement of very rapid movements. Furthermore, the nuisance to the examined subjects is minimal (they are not obliged to walk barefoot, or without clothes) [1, 48–51].

The force plates are usually placed near one another. This is a negative aspect of the technique, because the examined subjects usually have to alter their gait, so as to perform two consecutive steps on the two force plates [52, 53].

Accelerometry

Accelerometer signals are frequently used for the analysis of human gait. Although in many studies such devices are attached to the lower back [54], they are also attached to the limbs to characterize walking pattern and movement coordination [55], or to detect different phases of walking [16].

Apparatuses for accelerometer studies may be commercial or laboratory constructions [56]; the choice depends on each laboratory's needs and funding.

Conclusions

A number of gait analysis techniques have been reviewed. Some are costly, others not. Some offer much information regarding human gait, others not. I believe that the simplest technique should be chosen and applied in a research laboratory as a start for gait analysis. Progress to more composed and sophisticated techniques should be made when experience, technical support and innovation are acquired.

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