# GAIT ANALYSIS: TECHNICAL NOTES



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## ABSTRACT

*Biomedical technologies are having an increasingly central role in the modern medicine. In fact they are at the root of the diagnosis and follow up of pathologies giving to the clinicians quantitative outcomes necessary on the choice of the right therapy. In this paper we will focus on biomedical technologies used in the context of gait analysis describing the main ones used in the clinical practice about pathologies of neurologic, orthopedic and rheumatic interest and underlining their importance in the clinical setting. The main systems for gait analysis will be presented in this article: system with passive markers, stereophotogrammetric system, force and pressure platforms, surface electromyography system, system based on inertial measurement units underling the importance of each in investigating a different aspect of movement and how integrating all of them we can have a depth and whole gait analysis. The main gait analysis protocols will be presented too. Finally, advantages and disadvantages about gait analysis will be analyzed. In conclusion, the complexity of the described biomedical technologies for gait analysis underlines the importance of the presence of an expert technician that can help the clinician to interpret and to process acquired signals during the gait analysis.*



## INTRODUCTION

In a clinical setting, Gait Analysis (GA) or computerized gait analysis allows to record, quantize and monitor over time patients walking with different disease of neurological, orthopedic and rheumatic interest. It has become in the last years a valid tool available to the clinician as support to the evaluation of the patient's disorders and to follow over time the pharmacological and/or rehabilitative program, assisting in the choice of possible therapeutic adjustments. In fact, having the possibility to monitor quantitatively the movement of the patient leads to the possibility to measure accurately the effects produced by a given drug therapy, surgery and/or rehabilitation. It is also possible to evaluate the use and effectiveness of an orthoses specifically for each patient. It is proposed to record walking through the use of several integrated and interfaced instruments, each with the purpose of investigating a different aspect of movement: video footage with multiple cameras to reconstruct movement in three spatial dimensions; force and pressure platforms to measure the energy exchanged with the ground; surface electrodes that allow simultaneous recording of the electrical activity of the muscle groups involved during the movement. It provides measurement of kinematic variables (position, velocity, acceleration) and dynamic variables (forces). Different systems are available for measuring kinematic quantities: electrogoniometers (angle measurements between joints), accelerometers (measurements of accelerations of body segments), and by far the most used, optoelectronics using cameras that record the movement of markers placed on the subject's body surface.

## METHODS

Several protocols (SAFLo1,DAVIS2,CAST3, and others) are used to acquire a standardized and repeatable analysis; the most common acquisition protocol is the DAVIS system, which includes the following steps:

1. Perform anthropometric measurements: height, body weight, and bone segment parameters necessary to estimate joint centers (for example the distance between the right and left anterior and upper iliac spines, the distance in the sagittal plane of the anterior iliac spines and the great trochanter, etc.)
2. After having positioned the marker on the body surface, a static acquisition is made: the subject remains in an upright position for about 2-5 seconds during which the markers position in the space are acquired. These measurements, integrated with the anthropometric ones, allow to calculate the reference systems related to the bone segments and the position of the joint centers of the lower limbs
3. Finally, a dynamic acquisition of the motor acts of interest is carried out. The path that the subject makes is about 10-15 meters, repeated sev-

Figura 1 – Adhesive electrodes with circular surface.

eral times (usually 3-5 times) in order to have a number of steps adequate for a correct statistical analysis. Usually during the path steps on force/ pressure platforms or more rarely on 2 or more steps of standard size are expected.

The typical instrumentation is the following

- Passive markers: disk or sphere with a diameter of about 1 cm2 made of retro-reflective material placed in standardized landmarks on the subject's body by means of bioadhesive material. To receive a stable signal, the sensor must be placed on a point where maximum visibility is guaranteed; there is no overcrowding of markers that hinder the identification of the single trajectory; at least 3 markers are used to identify a body segment.
- Infrared camera system (usually 6-8: 2 anterior, 2 posterior and 2 or 4 lateral respect to the path able to record the light signal from the markers and to transduce it in a digital signal. The latter is sent to an acquisition card, where the different signals are integrated and sent to computer processing system.
- Pressure/force platforms able to measure the forces exchanged between the patient and the ground. Knowing the system of forces exchanged to the ground and acquired kinematic parameters through optoelectronic systems, it is therefore possible to calculate the moment of forces and the power to the different joints.
- Surface electromyography system (sEMG): the surface electrodes (Fig. 1) attached to the patient's skin record the bioelectric signal due to muscle contraction. The recommended recording is bipolar. To improve the signal-to-noise ratio, it is first necessary to improve the signal using a cable with an integrated pre-amplifier. In addition, to lower the impedance it is necessary: ensure a good contact between electrode and skin (less artifacts, reduction of electrical interference); avoid the imbalance between the impedance of the two electrodes (less common mode interference). It is therefore advisable to shave and thoroughly clean the skin of the subject at the point where the electrode will be placed. In addition, it is recommended to use elastic bands or adhesive tape for the fixing of electrodes and cables, so that joint movements do not apply traction on cables and electrodes (reducing artifacts). Factors that influence the quality of signal recording are the presence of neuromuscular junction, muscle-tendon joints or other active muscles in the vicinity of the chosen position (cross-talk). For a correct acquisition of movements of bilateral body segments (such as walking) it is essential to apply the electrodes symmetrically to the homologous muscles of the two sides and to maintain the same interelectrodic distances. The position of the electrodes longitudinally to the muscle is recommended and preferably between the proximal third and distal two-thirds of the muscular abdomen (Fig. 2). For recording lower limb muscles, the electrodes must not have a diameter greater than 10 mm because an increase in the transverse dimension with respect to the orientation of the muscles fibers on the one hand could be increase the recorded volume but on the other hand reduce the acquisition accuracy as it could also record from contiguous muscles (cross-talk). The raw bioelectric signal (sampling frequency of at least 1000 Hz) (Fig. 3) is sent wireless in real time to an acquisition system and then processed using dedicated software (off-line) (Fig. 4).
- Foot-switche (Fig. 5-6): the acquisition protocol also provides for the recording of signals to identify the different steps phases through the application of additional electrodes on the sole of the foot. The obtained signals clearly show the typical alternation of stance and swing phases related to the gait cycle. Formally we identify the initial phase of the step with the beginning of the contact of the heel on the ground. In this way, the gait cycle analysis allow to identify the intervals in which to search for the muscular activations of the lower limb.

Figura 2 – Bilateral positioning of surface electrodes on lower limb muscles posteriorly and anteriorly.

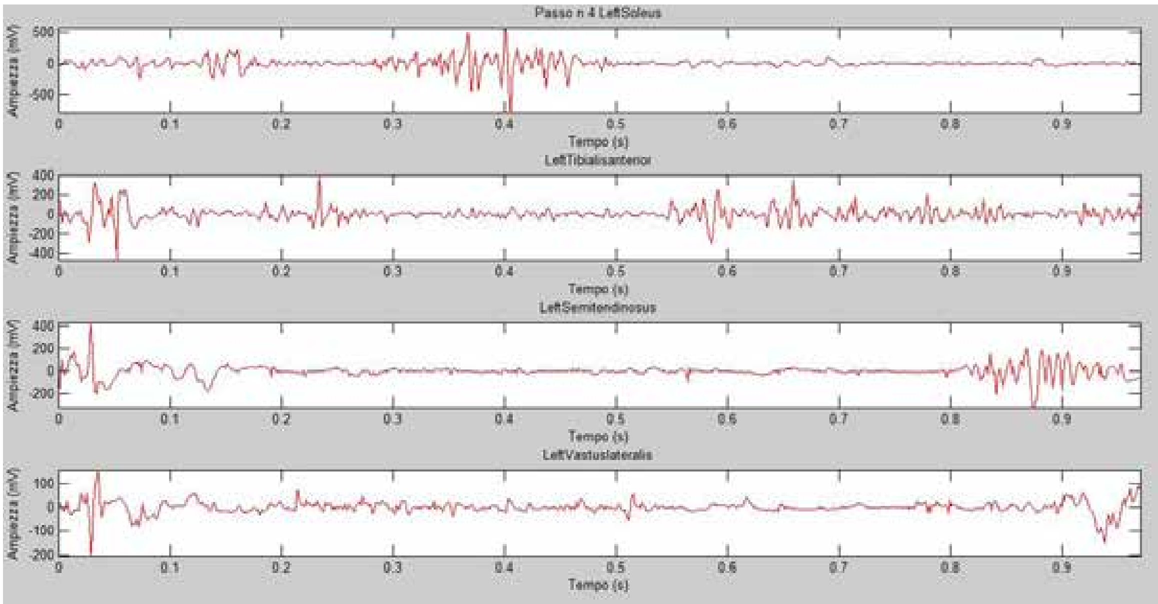


**Figura 3** – Acquired raw electromyiographic signal related the muscles of the left lower limb.

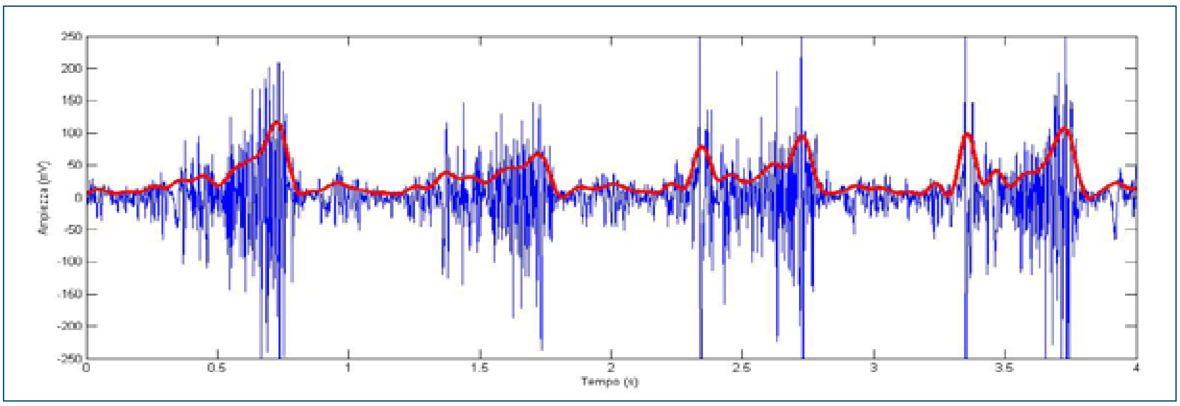


**Figura 4** – Processing: resulting envelopes, overall display on a sequence of four steps.

- Finally, the computer system with specific software collects, processes and stores the signals obtained from the different acquisition systems (cameras, platforms, electrodes). From the three-dimensional coordinates of the markers, this system integrates the digital signals and reassembles a three-dimensional image of the subject. The time sequence of these images is the faithful reproduction of the kinematic motion of the joint and it is possible to analyze the muscular electrical activity the and force/energy produced by the muscle groups involved in that particular joint displacement.

From this it can be seen that the neurophysiopathology technician is active during the acquisition phases of the traces mainly for his competences regarding the positioning of the electrodes and for the interpretation of the signals acquired during the gait cycle phases. Moreover also in the data processing stages has a determining role, assisting the doctor in identify the muscles most deficient or the activation pattern of the muscles during the gait and therefore to orient the therapeutic choice (botulinum, orthoses, surgical elongation of tendons, etc.)

## CONCLUSION

GA is a very interesting method in the clinical-rehabilitation field because it allows to measure quan-

**Figura 5** – Electrode positioning for foot switch analysis.

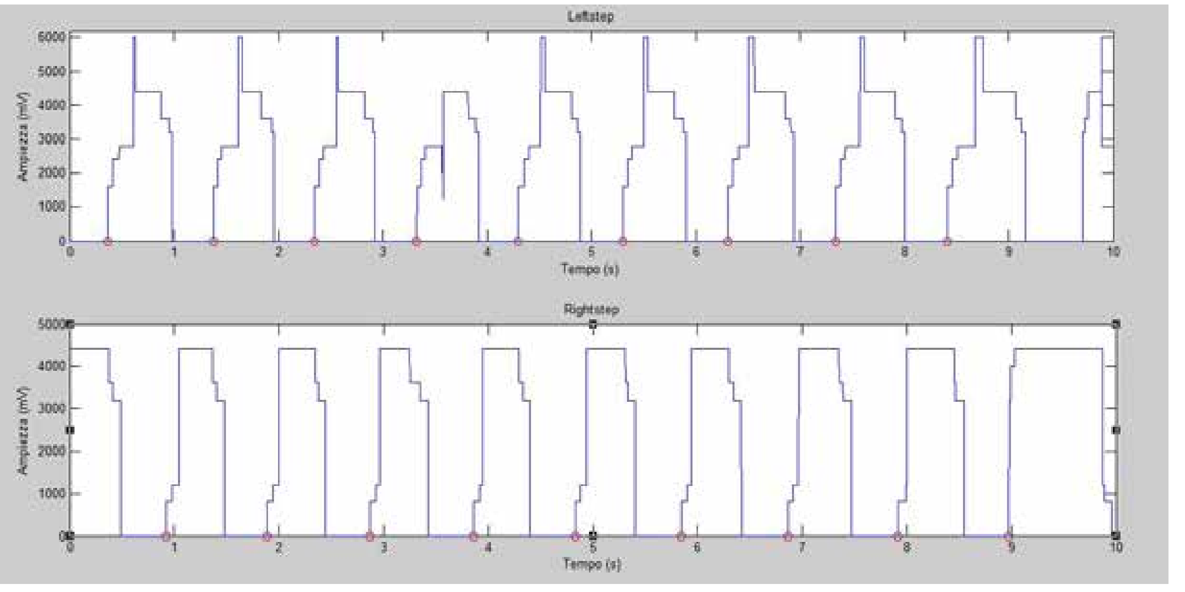


**Figura 6** – Foot-switch signals, right and left.

titatively not only the kinematic aspects of human movements but also dynamic and electromyographic aspects of fundamental importance in the overall evaluation of the patient. This leads the clinician to a more detailed vision of the patient's condition and consequently to the analysis of a course of therapeutic/rehabilitation more targeted to the patient's need. The advantages are: a non-invasive method, therefore repeatable over time; patient-oriented that is the system can be adapted to motion disorders of the patient (hemiparesis, dystonia, polyneuropathy) and to the evaluation of the use of orthoses; provides objective data and therefore comparable between different assessment teams. The possible disadvantages are: the costs in terms of purchase of the instrumentation; the dedicated staff must possess specific expertise; it is a time-consuming examination; the instrumentation could be bulky.

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