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A Picture Is Worth a Thousand Steps

Step by step, one foot in front of the other – the easiest thing in the world, right? In reality, the human gait is one of the most complex movements we perform. How can we describe it, and what can gait analysis tell us?

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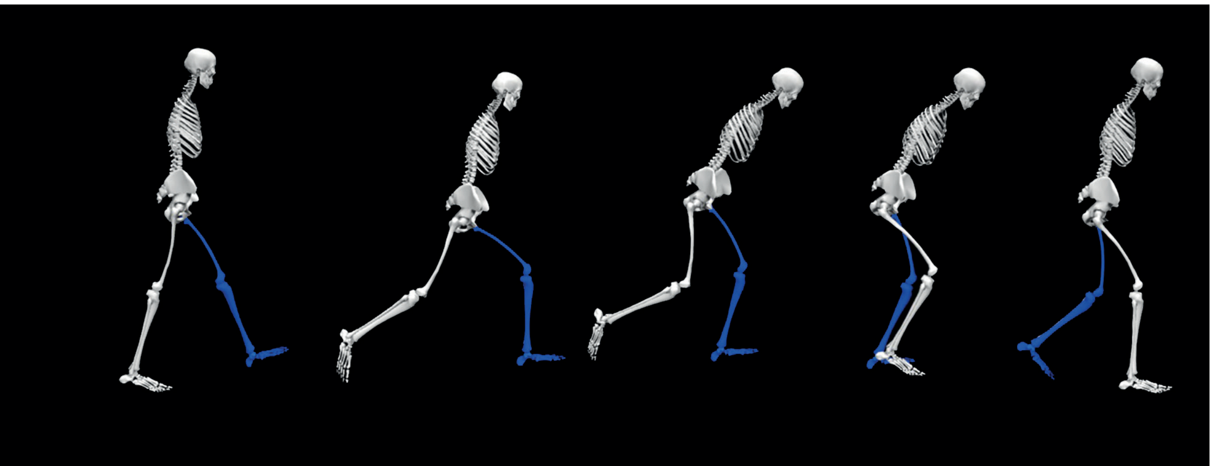
Walking is one of the first complex motor activities of the human body to appear during its development. Despite being considered obvious and natural, gait is actually one of the most complex movements performed by humans. Normal gait is defined as a series of precise, coordinated, repetitive movements of the limbs that serve to move the body from one place to another. It is characterized by rhythmic loss and recovery of bodily balance, through alternating phases of stance and swing, with the smallest possible energy expenditure.

The basic structural unit of gait is called the gait cycle. Each leg performs specific consecutive sequences, which are the same for the right and the left sides, and their mutual share in the gait cycle is 50%. Each gait cycle consists of two phases: stance and swing.

Normal gait requires a high level of very precise integration between the nervous system and the muscles. If any of the elements of this system becomes damaged as a result of injury, degeneration, or deformation, this immediately leads to gait abnormalities.

How is human gain analyzed?

Proper diagnosis of gait abnormalities is essential for clinicians and physiotherapists. It helps us to better understand basic movement control mechanisms and strategies, plan therapies, predict and evaluate the results of surgical treatment, assess the quality and fitness of prostheses, evaluate the functional status of patients after joint replacement surgeries, test motor



A typical reaction to slipping, after the left leg (in blue) steps on a slippery surface

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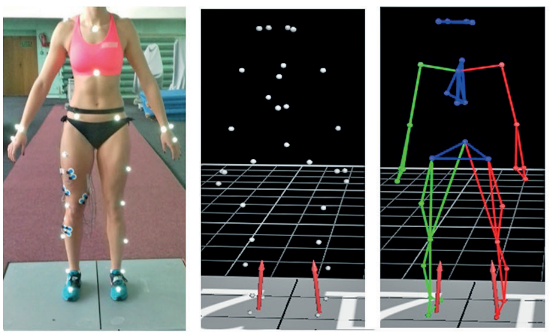

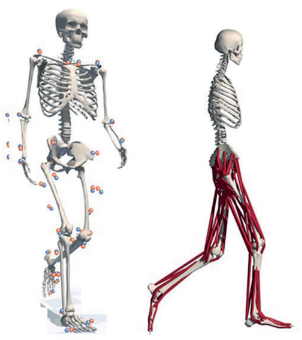

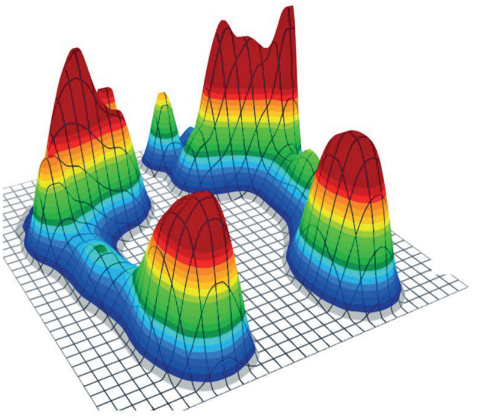

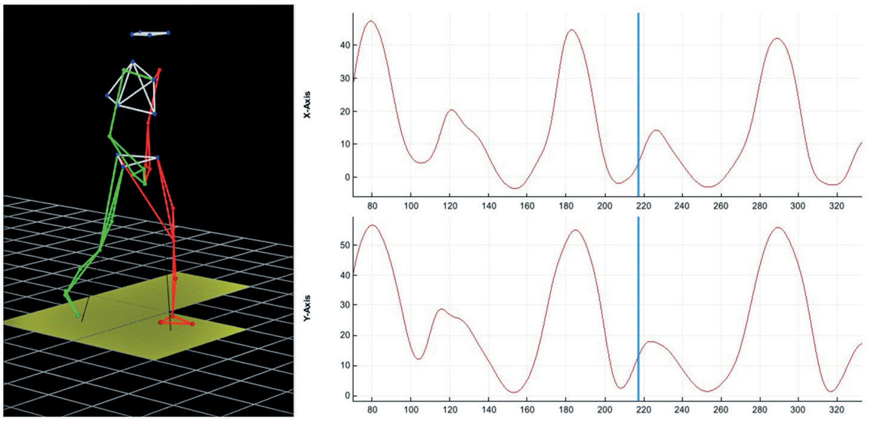

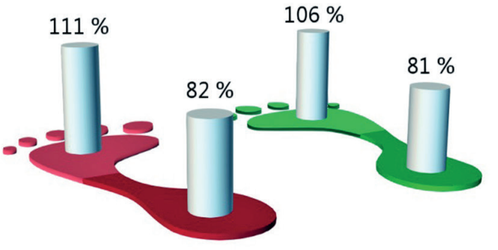

Kinematic parameters during a perturbation (a trip) in the initial contact phase during gait. The figure shows the data for one person during an attempted trip in the free initial contact phase, for the right and left sides of the body, respectively

function, monitor treatment outcomes, and identify abnormal movement patterns resulting from neurological pathology. Classifying abnormal movement patterns according to functional disorders allows clinicians to better adjust treatment methods to individual patients.

Abnormal gait patterns may be caused by deformities, contractures, muscle weakness, abnormalities of neural control, and pain. Even small changes in gait patterns may result in increased energy expenditure and secondary abnormalities. Proper selection of treatment methods requires the identification of functional compensation mechanisms and primary pathologies. A primary pathology is one that is present in the human body from birth or the early years of life. In turn, neglecting proper development or function (such as lack of physical activity and bad sitting habits) will lead to the development of functional compensation mechanisms. Functional compensation is a defense mechanism: the body cannot perform a specific movement, so it uses another, very similar movement to compensate for this inability. Unfortunately, this happens with increased effort of muscles that should not be active as much at this particular moment.

Gait analysis is performed to assess spatiotemporal, kinematic, kinetic, and muscle activity parameters. Temporal gait parameters, expressed in seconds or as a percentage of gait cycle time, are the most popular and extremely useful measures used to diagnose gait abnormalities. These parameters include the time it takes to complete one full gait cycle (stride duration) and the duration of individual phases. The parameters used to perform a spatial assessment of gait are as follows: step length, stride length (one gait cycle), foot progression angle (the angle between the long axis of the foot and the direction of motion), and step width (the distance between the heels when both feet are on the ground). Importantly, the most commonly measured variable is gait velocity. The percentage share occupied by each phase of the gait cycle depends on age, body weight, and height. Aging is associated with a decline in stride length and cadence (number of steps per unit of time) and an increase in the double-support period. Similar results were observed in people with greater body weight and lower height.

Kinematic parameters reflect the geometry of motion, without regard to the forces that produce it. These parameters include joint ranges of motion, joint angles, as well as angular and linear velocities and accelerations. Kinetic parameters, in turn, describe the movement of the human body from the perspective of the forces applied. The most commonly analyzed kinetic parameters include changes in the vertical component of the ground reaction force during free gait with three clearly marked phases: the weight-acceptance peak, midstance, and the push-off peak.

Muscle activity is estimated using surface electromyography (sEMG). It evaluates muscle function and conduction in the peripheral nerves by analyzing the myoelectric signals produced by physiological changes in the state of the cell membranes of muscle fibers. All these parameters make it possible to perform objective analyses of human gait.

There are many measurement methods that support the subjective assessments performed by clinicians. The most popular include: podoscopes, dynamometric, strain gauge-based or piezoelectric force platforms, optoelectronic methods (camera systems), electrogoniometers, accelerometers, and the aforementioned surface electromyography. Selecting the right measurement method appears crucial for obtaining satisfactory results. Podoscopes are diagnostic devices for measuring foot pressure distribution. They make it possible to properly assess the shape of the foot, and therefore to quickly identify the degree of deformity. Dynamometric (strain gauge-based or piezoelectric) platforms allow the assessment of the ground reaction forces during gait and balance in a free-standing position on one or two legs. Accelerometers are simple devices mounted on the human body to measure motion velocity and acceleration.

Optoelectronic methods are the most comprehensive and advanced forms of assessing the movements of the human body. A system of cameras allows the actual analysis of movement at any moment in time, offering instant measurements of spatiotemporal and kinematic parameters. If such a system is synchronized with dynamometer platforms and enables the recording of EMG signals from relevant muscles, then we can talk about a full, comprehensive, and objective analysis of movement. Importantly, all the information we need is displayed on the computer screen in the form of images, which include more or less complex models of the person under study, and diagrams of joint angles, loads, and percentages.

Understanding trips and slips

In the Department of the Fundamentals of Physiotherapy at the Faculty of Rehabilitation, Józef Piłsudski Academy of Physical Education in Warsaw, in collaboration with the Regional Research and Development Center of the Academy of Physical Education's branch in Biała Podlaska, we attempted to assess gait stability in response to induced slips and trips in older adults over 60 years of age. To perform the measurements, we used the GRAIL system (Gait Real-time Analysis Interactive Lab, Motek Medical BV, NLD), an interactive laboratory for real-time gait analysis. GRAIL uses a dual-belt treadmill, a Vicon Motion Capture system, and a virtual reality (VR) environment with three video cameras.

Anyone, regardless of age, occupation, or health, may sometimes experience a slip or trip, which may lead to a fall. In many cases, falls may result in serious injuries, such as broken bones, and even in a concussion. A slip occurs when the feet lose traction with the ground on a slippery surface and start to move faster than the rest of the body. A trip, in turn, is typically a reflex of a certain carelessness in walking – the foot catches on an obstacle, which results in the foot becoming immobilized while the body keeps moving. GRAIL can produce momentary changes in the speed of one of the treadmill's belts, which made it possible to simulate trips or slips depending on whether the treadmill belt speeded up or slowed down. The results made it possible to identify the general characteristics of the body's response to perturbations depending on the gait phase. At this stage, we can draw very general conclusions about the reactions to induced slips on the left treadmill belt: the trunk leans forward, the body assumes a lunging position, and the right hip joint rotates externally. If a physically fit person trips up or slips, they generally recover their balance and return to normal locomotion after a few steps. But if this happens to a person whose neuromuscular system reacts much worse to unexpected situations, this may lead to a temporary overload of the musculoskeletal apparatus or, in the worst-case scenario, a fracture. Both situations will cause changes in locomotion and therefore a completely different load distribution in the joints, which can result in pain and a reduced quality of life. ■

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The GRAIL system for real-time gait analysis, including a treadmill, a motion-capture system, and a virtual reality environment

Further reading:

Arvin M., Mazaheri M., Hoozemans M.J.M., Pijnappels M., Burger B.J., Verschueren S.M.P., van Dieën JH., Effects of narrow base gait on mediolateral balance control in Young and older adults, *Journal of Biomechanics* 2016.

Roeles S., Rowe P.J., Bruijn S.M., Childs C.R., Tarfali G.D., Steenbrink F., Pijnappels M., Gait stability in response to platform, belt, and sensory perturbations in young and older adults, *Medical & Biological Engineering & Computing* 2018.

Yagi M., Ohne H., Konomi T., Fujiyoshi K., Kaneko S., Takemitsu M., Machida M., Yato Y., Asazuma T., Walking balance and compensatory gait mechanisms in surgically treated patients with adult spinal deformity, *The Spine Journal: Official Journal of The North American Spine Society* 2016.