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Development of innovative training solutions in the field of functional evaluation aimed at updating of the curricula of health sciences schools

TEACH

MODULE: BIOMECHANICS OF GAIT

Didactic Unit A: BIOMECHANICS OF NORMAL GAIT

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AMSE THE ASSOCIATION OF MEDICAL SCHOOLS IN EUROPE

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- Muscle work during walking
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OBJECTIVES

- Find out how gait is defined.
- Learn how gait is described - division into phases.
- Find out what the attributes and determinants of gait are.
- Find out what kinematic parameters are used to describe the biomechanics of gait and what changes these parameters subject during the gait cycle.
- Find out what dynamic parameters are used to describe the biomechanics of gait and what changes these parameters subject during the gait cycle.
- Find out what muscle work looks like during a gait cycle.

OUTLINE OF THE HISTORY OF BIOMECHANICAL GAIT ANALYSIS

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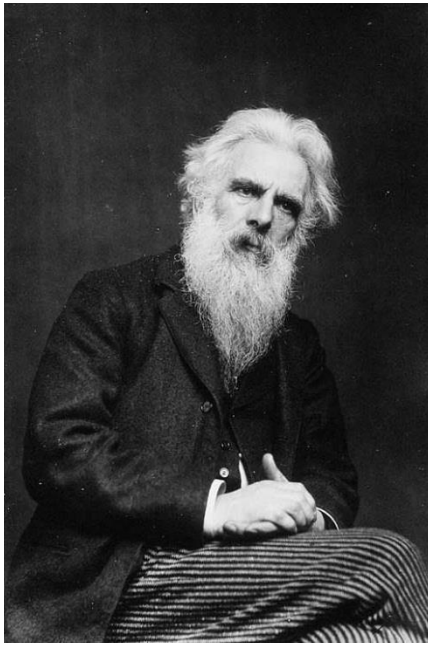
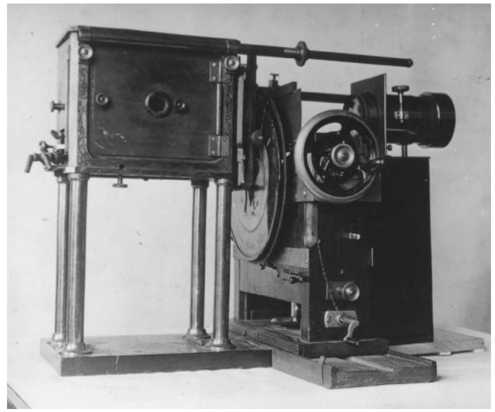
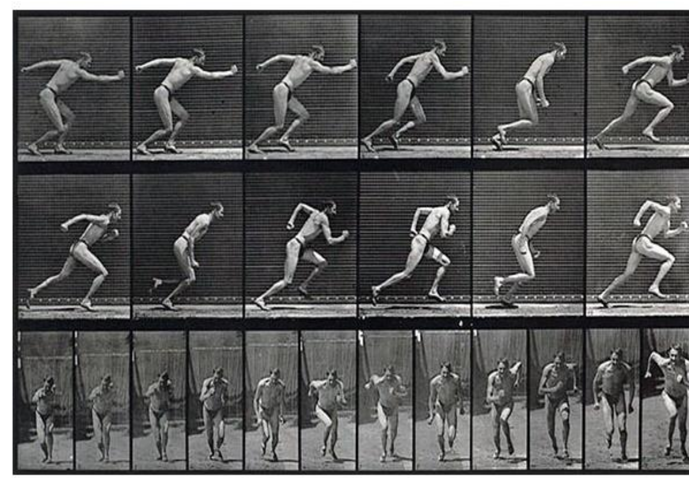


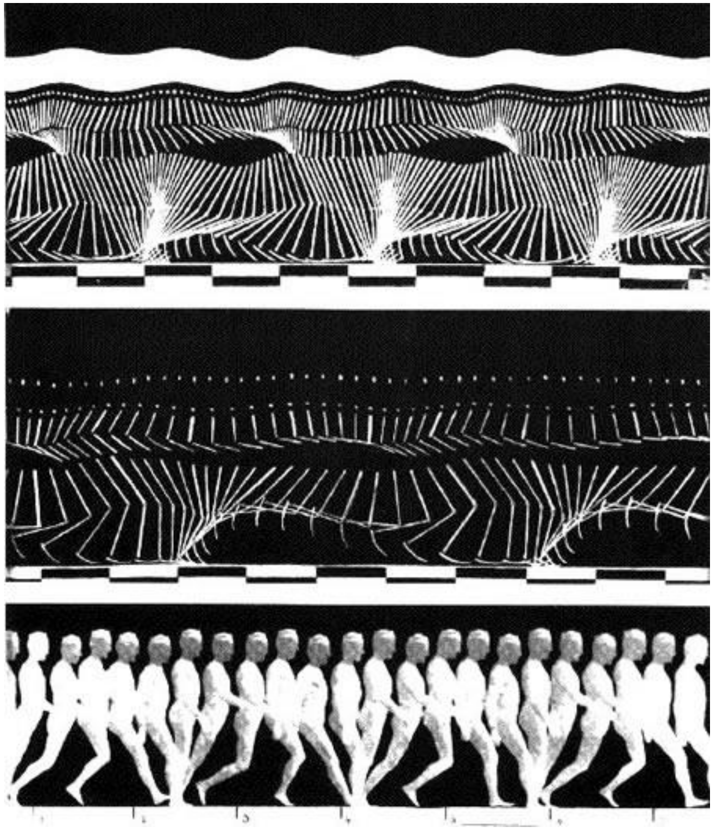


Equipment used by Mybridge to conduct research



Eadweard Muybridge (1830-1904)

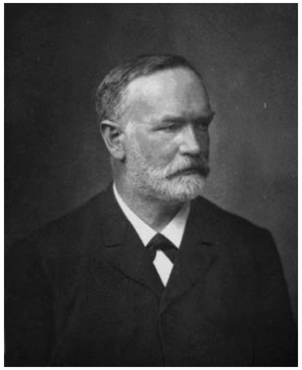
OUTLINE OF THE HISTORY OF BIOMECHANICAL GAIT ANALYSIS

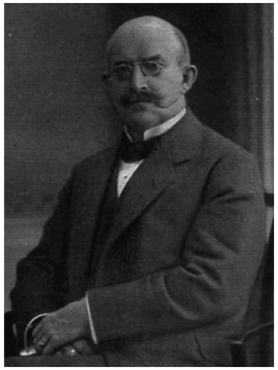


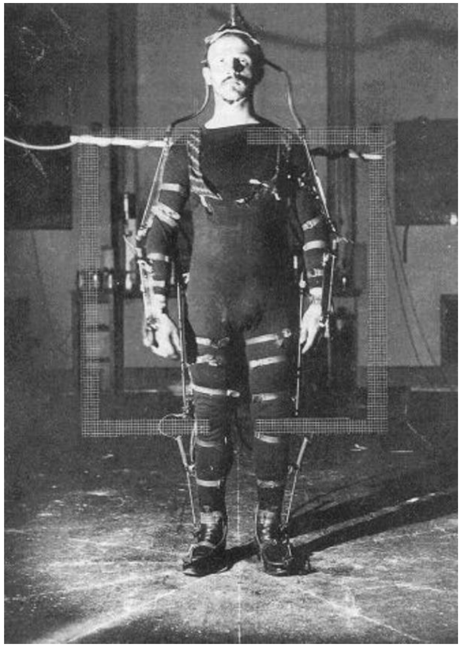
The suit used by Marey and subsequent gait sequences recorded (1883)

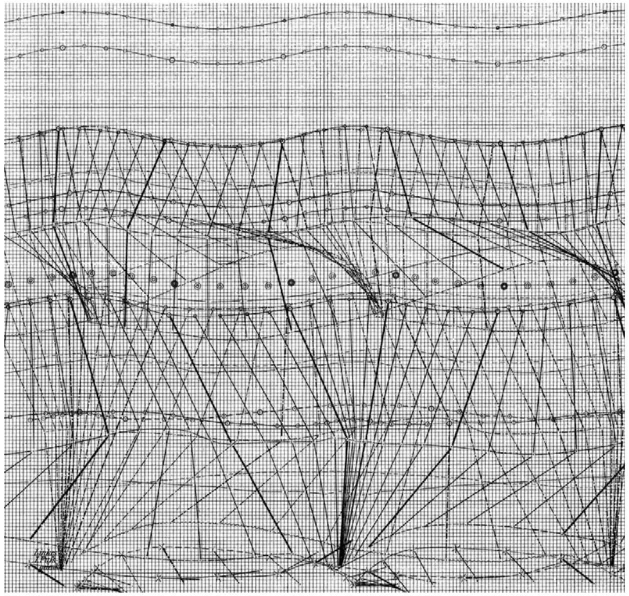
Etienne Jules Marey (1830-1904)

OUTLINE OF THE HISTORY OF BIOMECHANICAL GAIT ANALYSIS









Wilhelm Braune (1831 – 1892)
i Otto Fisher (1861 – 1917)

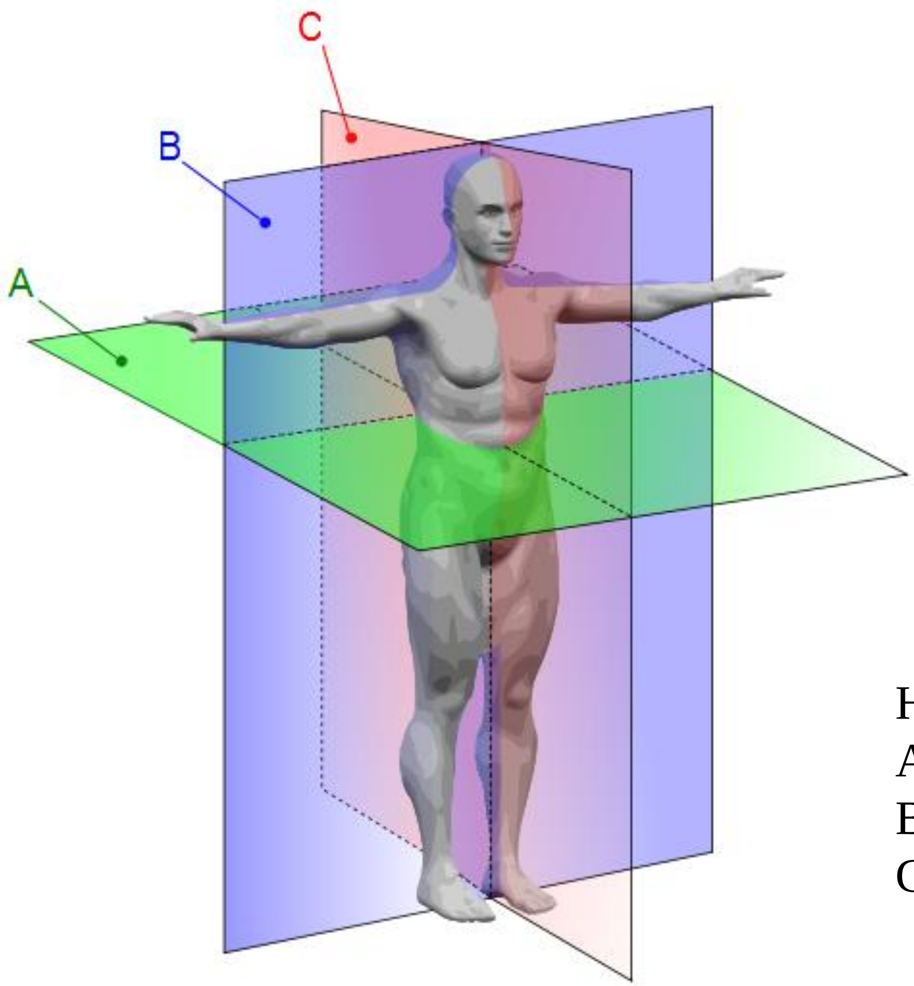
The suit and hand chart of subsequent lower limb positions (1891) - Fisher and Braun study

NORMAL GAIT - BASIC DEFINITIONS

NORMAL GAIT - BASIC DEFINITIONS

- Morecki defines locomotion as a movement leading to a change in the place occupied by an object in relation to the adopted reference system.
- On the other hand, Błaszczyk defines the concept of human locomotion as follows: „Locomotion is a process of active movement of organisms associated with the implementation of specific life needs.
- Gait according to Dega can be defined as alternating loss and regaining balance in alternately changing phases of support and swing of the lower limbs
- Depending on the speed range, the bipedal locomotion can be divided into several forms differing in the coordination of movements of individual body segments: gait, run, sprint, jumps."

NORMAL GAIT - BASIC DEFINITIONS



Human body main planes
A – horizontal (transverse) plane,
B – frontal plane,
C – sagittal plane

NORMAL GAIT - BASIC DEFINITIONS

Biomechanical gait analysis is usually carried out on the basis of the so-called gait cycle using the values determined during experimental tests and using mathematical models. Gait analysis is most commonly assessed in biomechanical analysis by means of:

- gait attributes
- determinants of gait,
- temporally-spatial parameters,
- kinematic parameters,
- ground reaction forces,
- muscle bioelectric activity,

NORMAL GAIT - BASIC DEFINITIONS

- values of moments of muscular forces acting in the joints,
- the values of forces generated by muscles,
- power,
- reactions in the joints.

DESCRIPTION OF THE NORMAL GAIT

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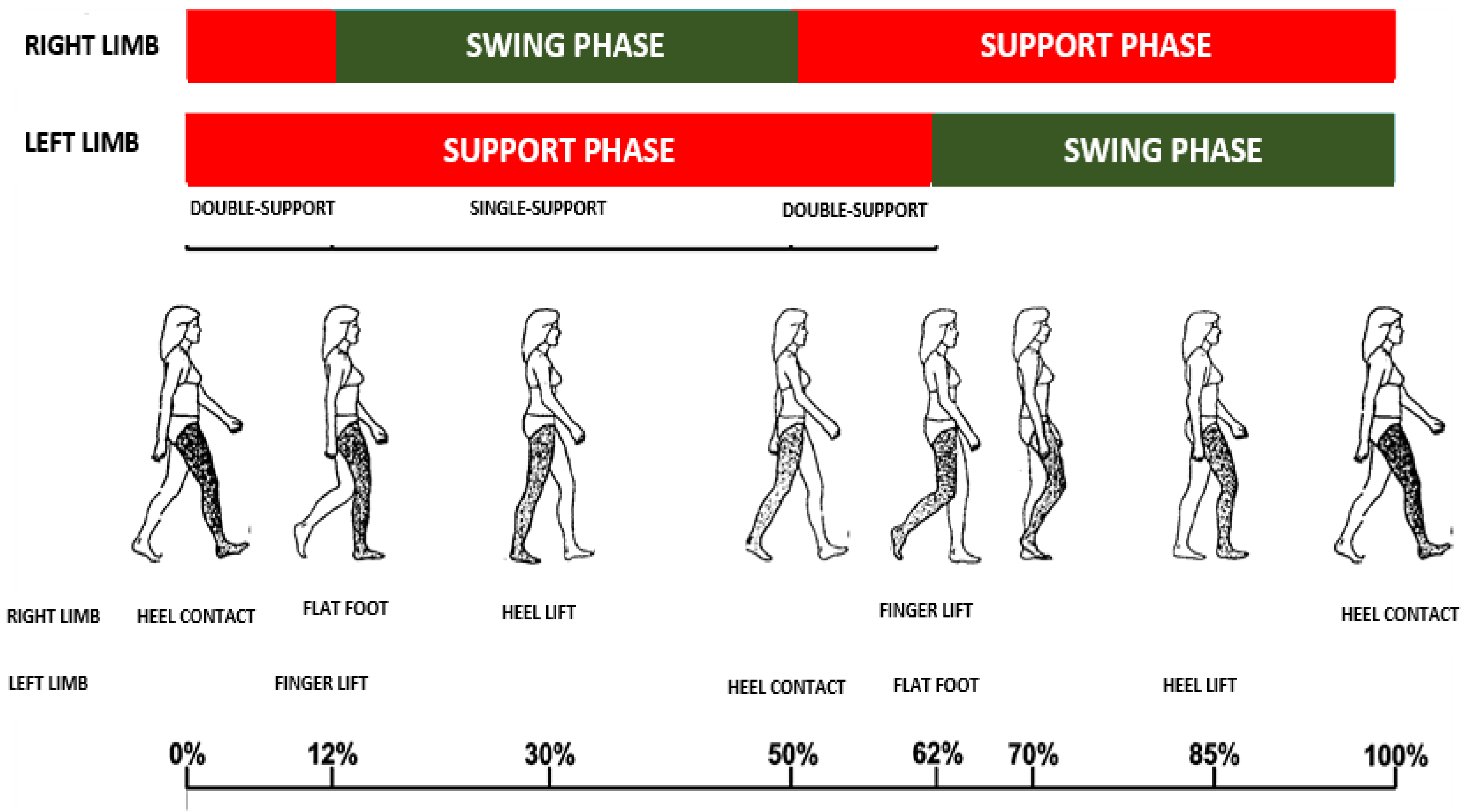
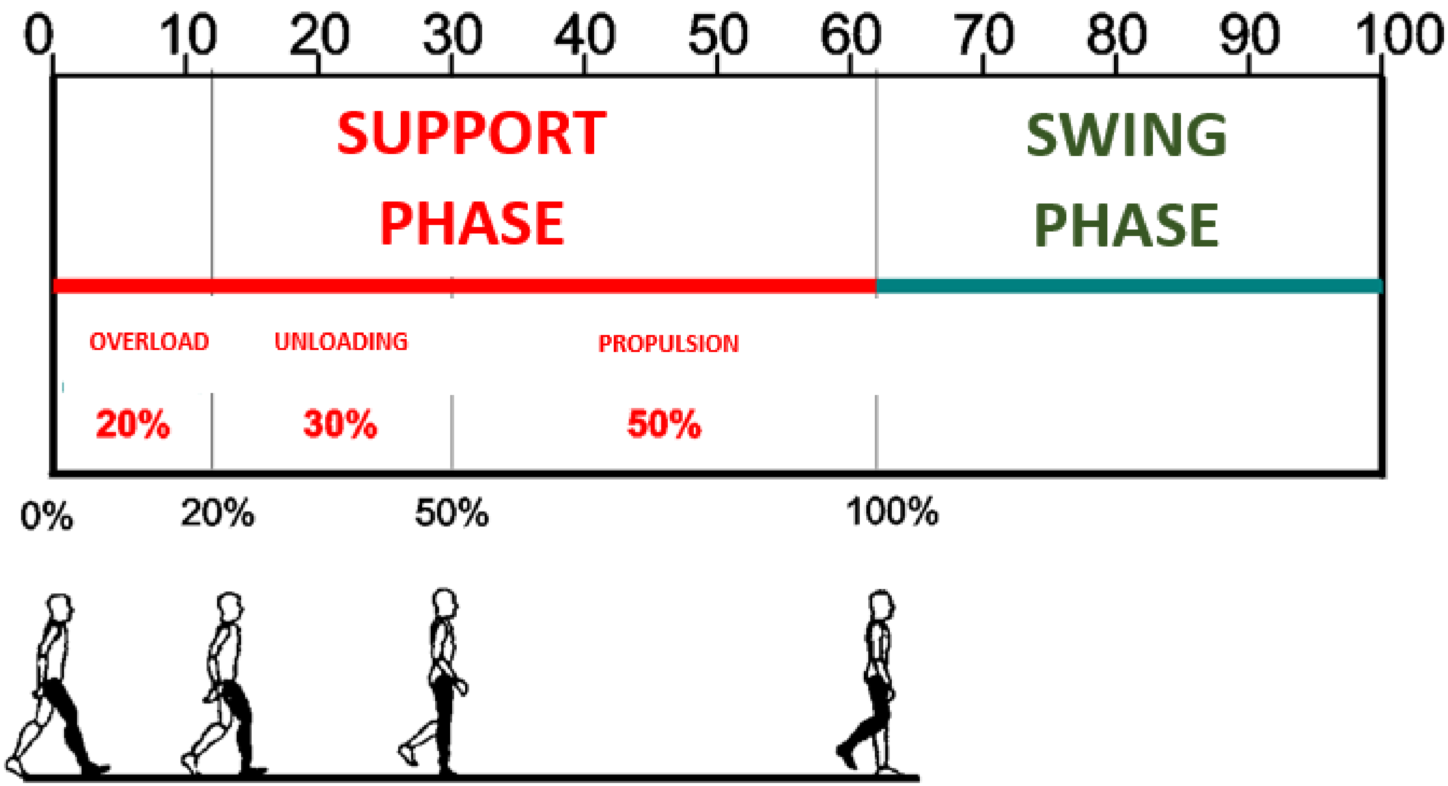


Gait cycle phases for the right and left limb

DESCRIPTION OF THE NORMAL GAIT



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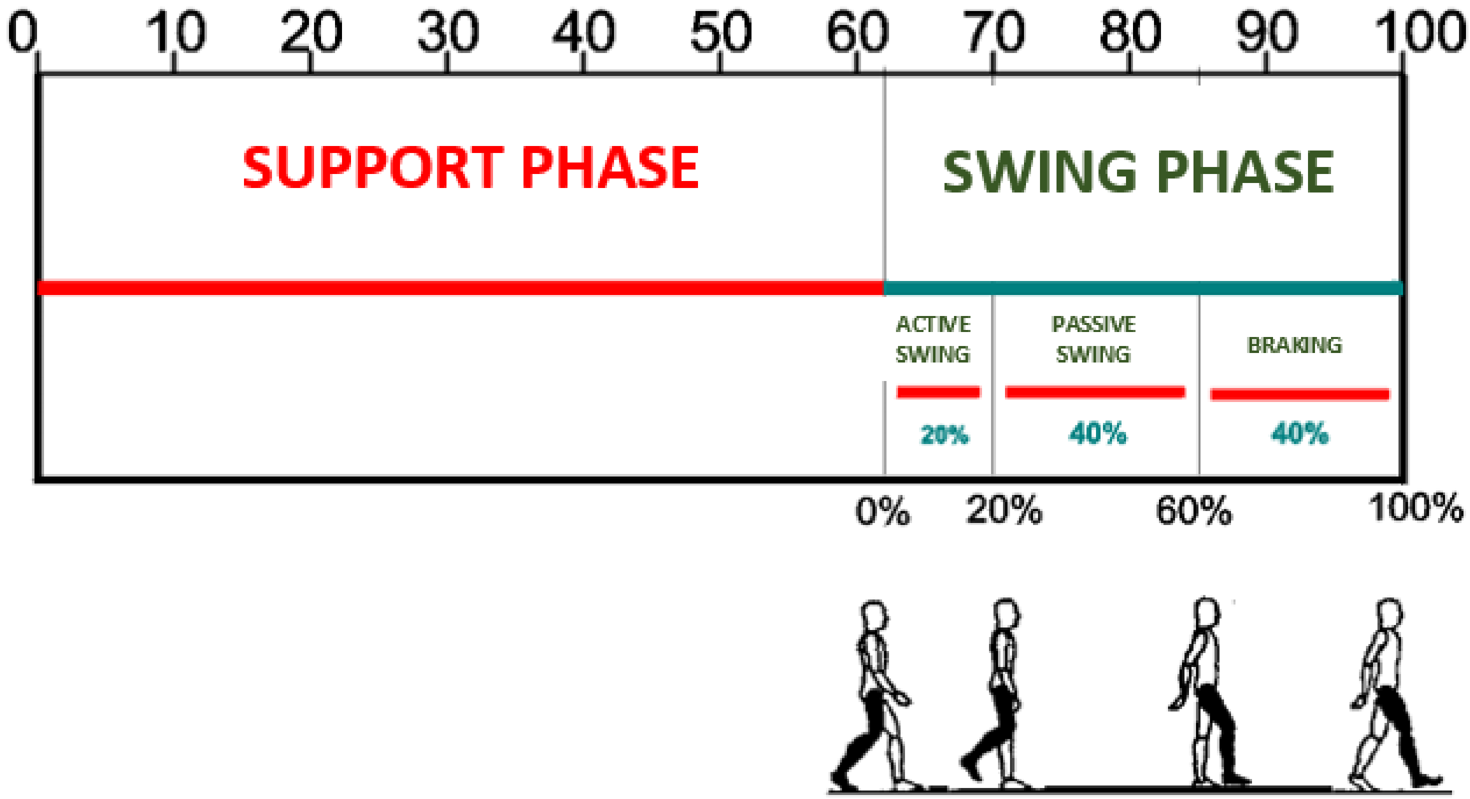


DESCRIPTION OF THE NORMAL GAIT

Walking at so-called volunteer speed is usually carried out at a speed of 4 km / h. At this speed, the walking cycle lasts about 1.1 seconds, while the individual phases, in relation to the entire walking cycle, last:

- support phase around 62% of the gait cycle,
- swing phase about 38% of the gait cycle,
- double support phase around 12% of the gait cycle.

DESCRIPTION OF THE NORMAL GAIT

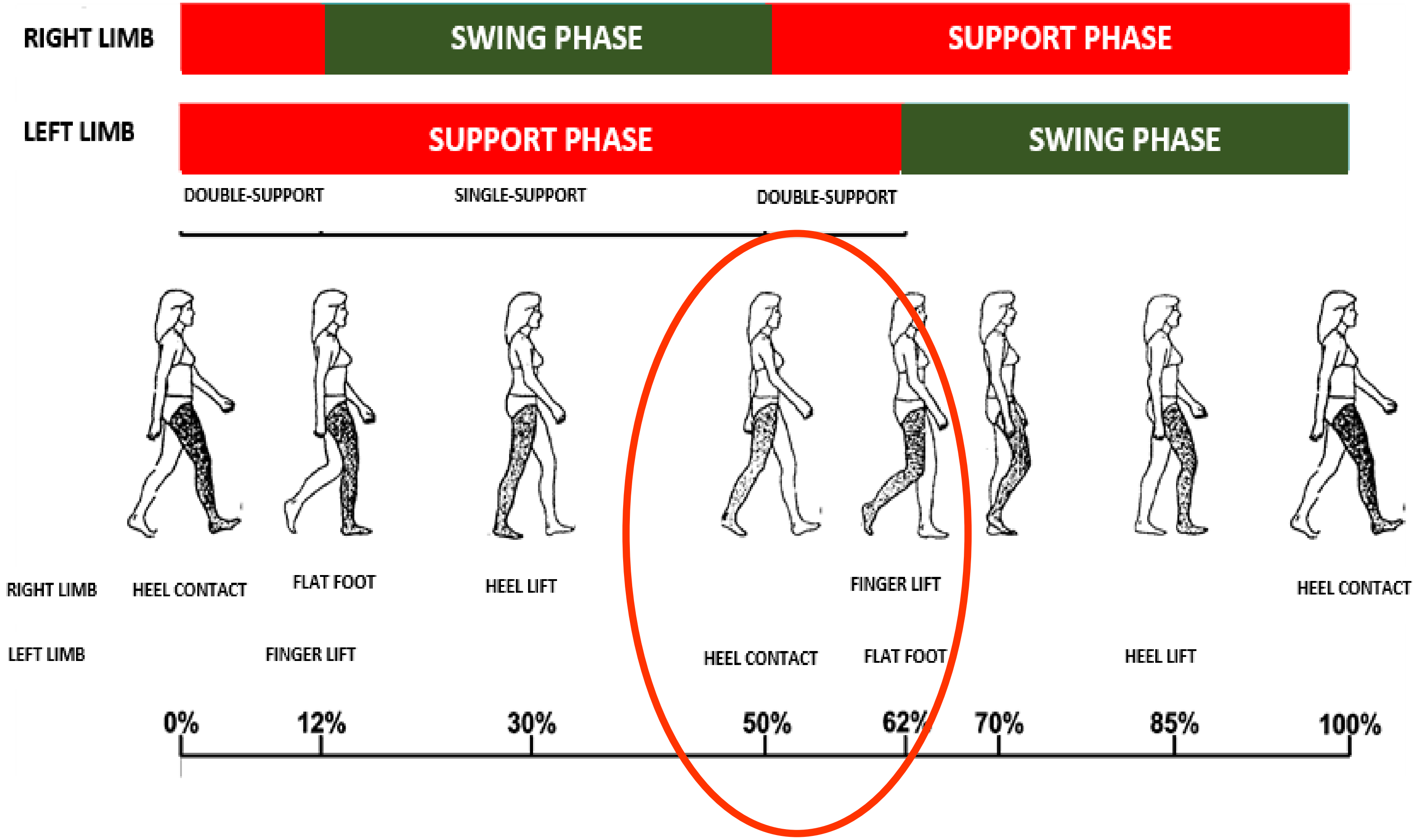
Division of the support phase:

- overload phase,
- unloading phase,
- propulsion phase.

Division of the swing phase:

- active swing,
- passive swing,
- braking phase.

DESCRIPTION OF THE NORMAL GAIT



Double-support phase lasts 10-12% of the gait cycle

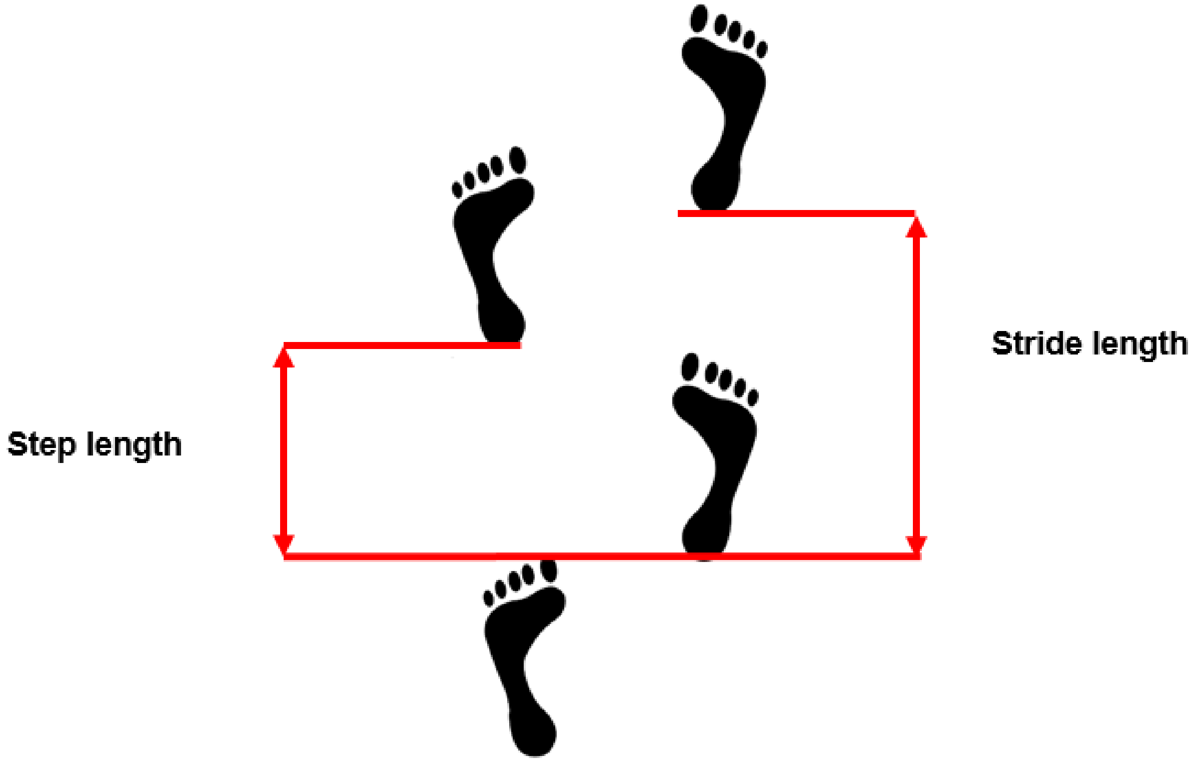
DESCRIPTION OF THE NORMAL GAIT

cadence – this is the number of steps taken in one minute. Studies have shown that the natural rhythm of locomotion in women is on average 122 steps per minute, while for men 116 steps per minute,

stride length – this is the distance between successive, same support points of the same limb, for example the points at which a given limb started the support phase or ended the swing phase,

step length – this is the distance between the selected but the same points of the right and left limb, for example the distance between the position of the heel of the right and left limb. The step length may be different for the right and left limb.

DESCRIPTION OF THE NORMAL GAIT



ATTRIBUTES AND DETERMINANTS OF NORMAL GAIT

ATTRIBUTES AND DETERMINANTS OF NORMAL GAIT

GAIT ATTRIBUTES

The following five walking attributes can be distinguished:

- support stability
- correct clearance under the foot during the swing phase, i.e. proper limb raising. About 18 cm is considered to be correct.
- appropriate positioning of the foot before the beginning of the support phase, which, when walking correctly, begins when the heel contacts the ground.
- appropriate stride length
- minimization of energy consumption.

ATTRIBUTES AND DETERMINANTS OF NORMAL GAIT

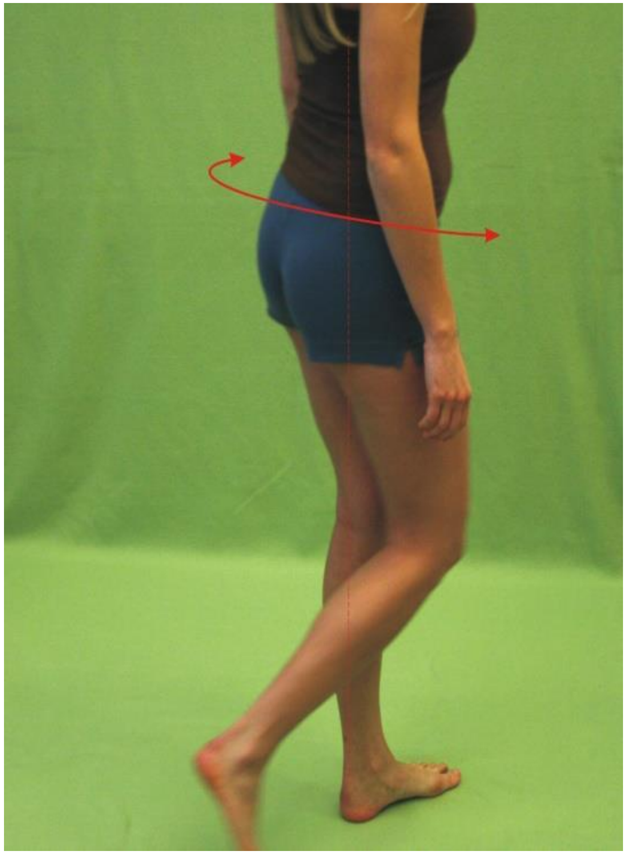
GAIT DETERMINANTS

There are six determinants of gait:

- Pelvic rotation in a horizontal plane
- Pelvic obliquity in the frontal plane
- Pelvic lateral movements
- Knee flexion during the support phase
- Functional shortening of the limb during the swing phase
- Foot movement and angular changes in the ankle joint in the sagittal plane

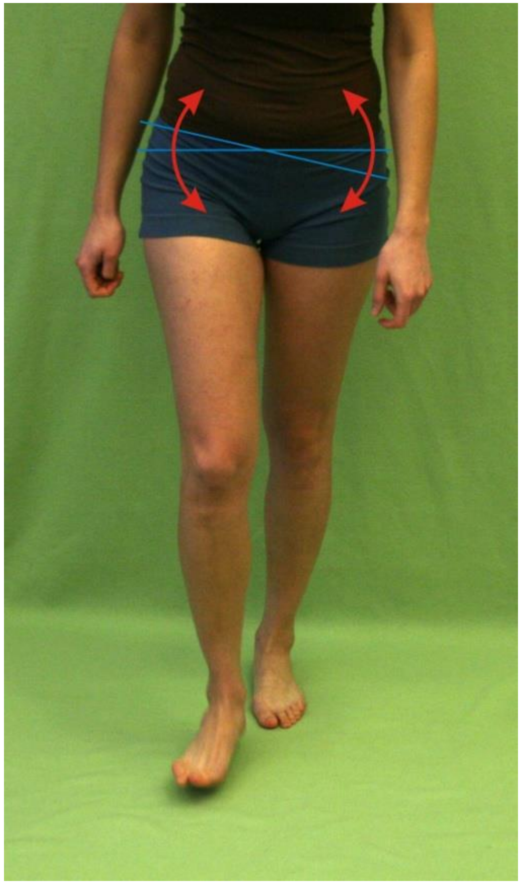
ATTRIBUTES AND DETERMINANTS OF NORMAL GAIT

Pelvic rotation in a horizontal plane



ATTRIBUTES AND DETERMINANTS OF NORMAL GAIT

Pelvic obliquity in the frontal plane

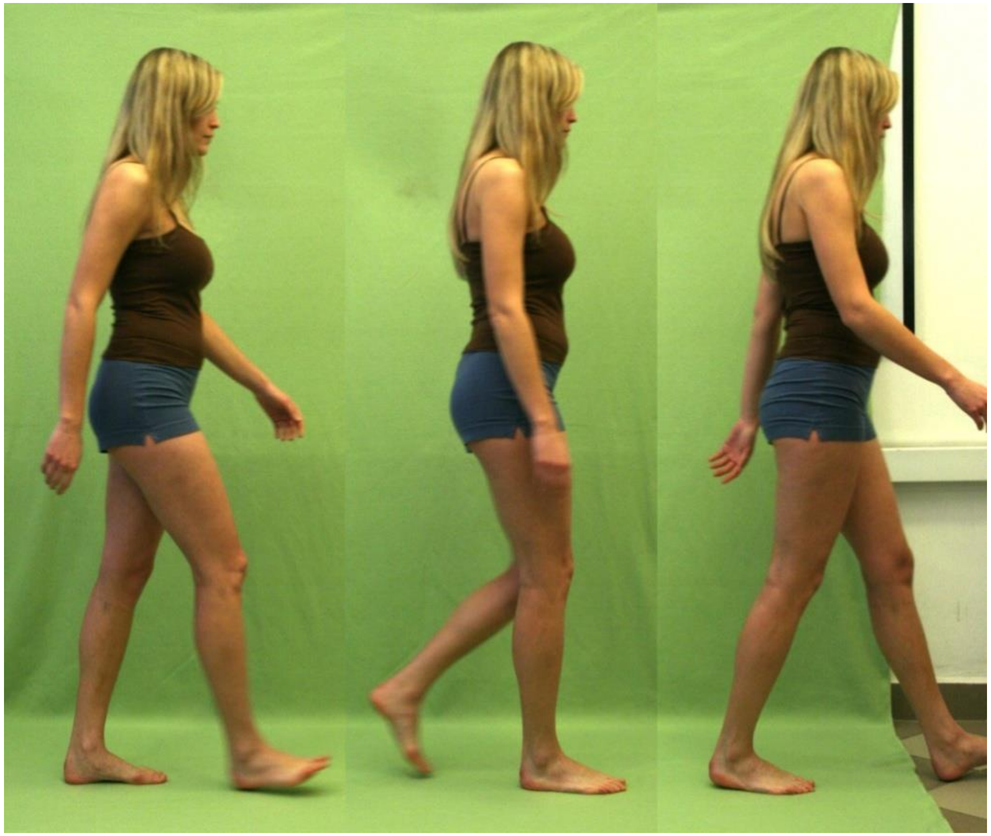


ATTRIBUTES AND DETERMINANTS OF NORMAL GAIT

Pelvic lateral movements

ATTRIBUTES AND DETERMINANTS OF NORMAL GAIT

Sequence of flexion and extension movement in the knee



ATTRIBUTES AND DETERMINANTS OF NORMAL GAIT

Functional shortening of the limb

ATTRIBUTES AND DETERMINANTS OF NORMAL GAIT

Foot movement and angular changes in the ankle joint in the sagittal plane

Correct positioning of the foot, i.e. the correct angle in the ankle joint, when the heel hits (dorsiflexion) and when the limb is detached from the ground (plantar flexion) increases the effective length of the lower limb.

ATTRIBUTES AND DETERMINANTS OF NORMAL GAIT

Conditions of the correct gait

A correct gait must meet the following conditions:

- the steps of both lower limbs must be of the same length,
- the loading time for both lower limbs must be the same,
- proper coordination of the entire torso and upper limbs with the work of the lower limbs must be ensured. It consists in the fact that simultaneously with the inclination of the lower limb there is a rotation of the torso towards this limb combined with a swing of the upper limb on the same side as the lead leg,
- heel contact with the ground is connected with the movement of the foot, which movement ensures correct positioning of the lower leg and thigh in external rotation,
- detachment of the foot from the ground is accompanied by the adduction of the foot, which movement begins the internal rotation of the lower leg and thigh.

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS

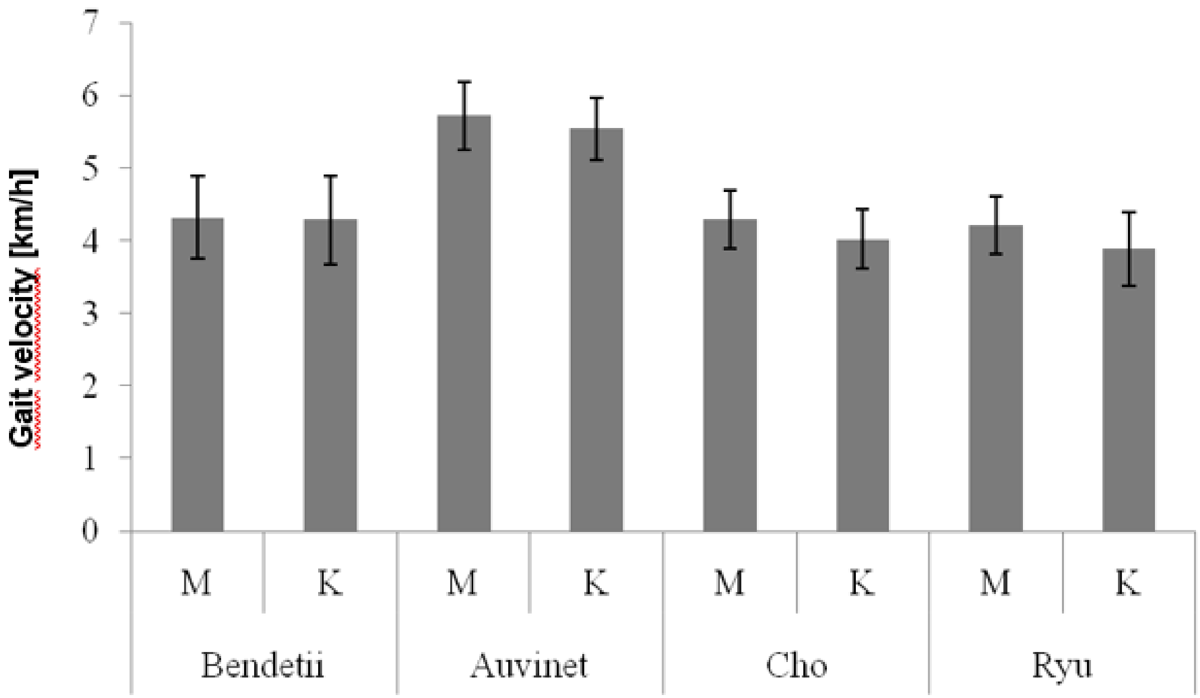
The basic values describing the gait include time-space values. These values can be determined using very simple measurement methods; therefore they belong to one of the most often determined and analyzed values. You can include them:

Gait velocity – average walking speed of healthy people varies between 4 - 6 km / h

Cadence – frequency of steps is about 90-120 steps per minute

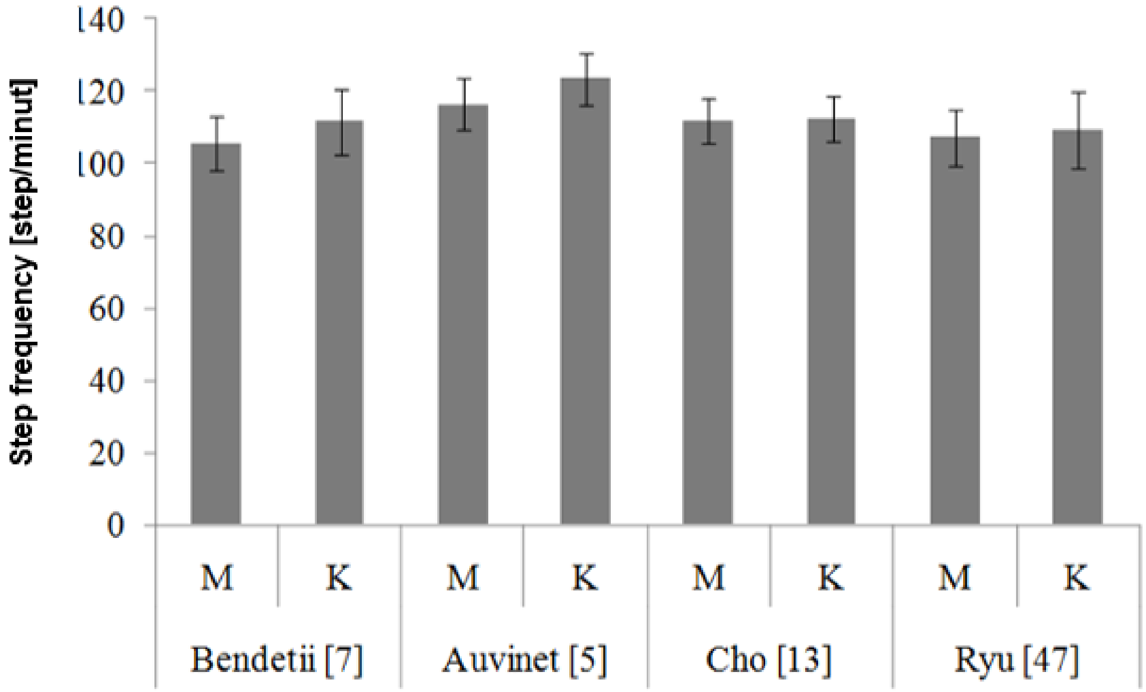
Stride and step length – average length of a single step of an adult is about 0.7-0.82 m

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS



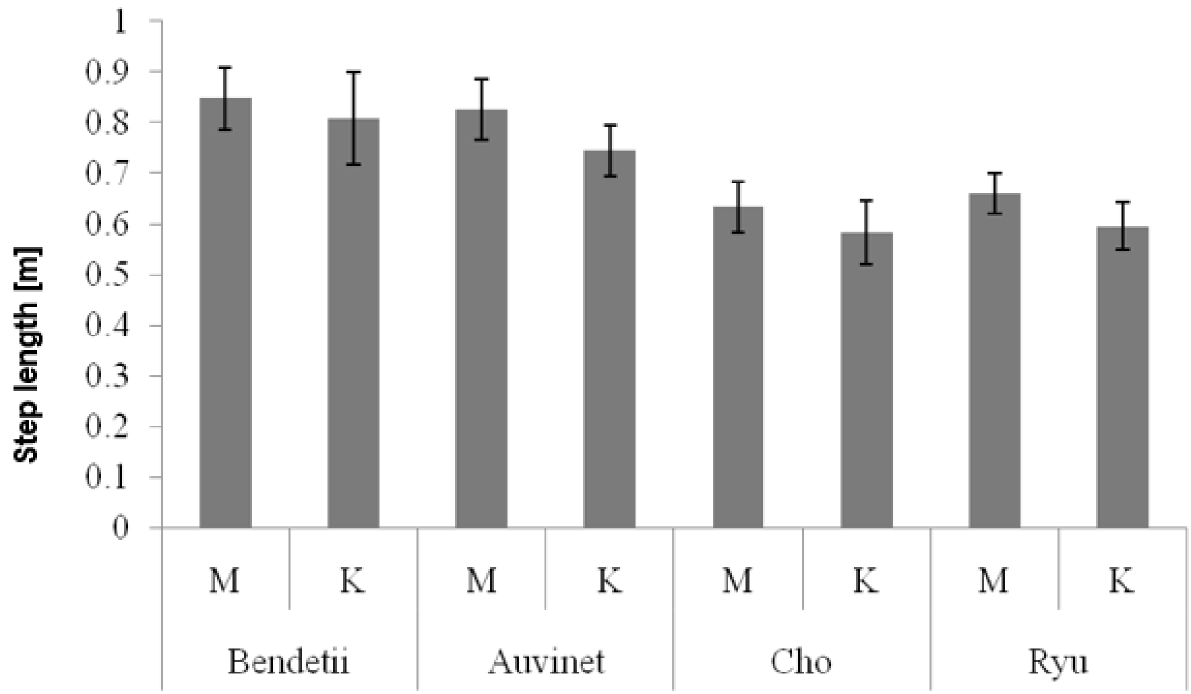
Gait velocity according to various studies with division into women and men

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS



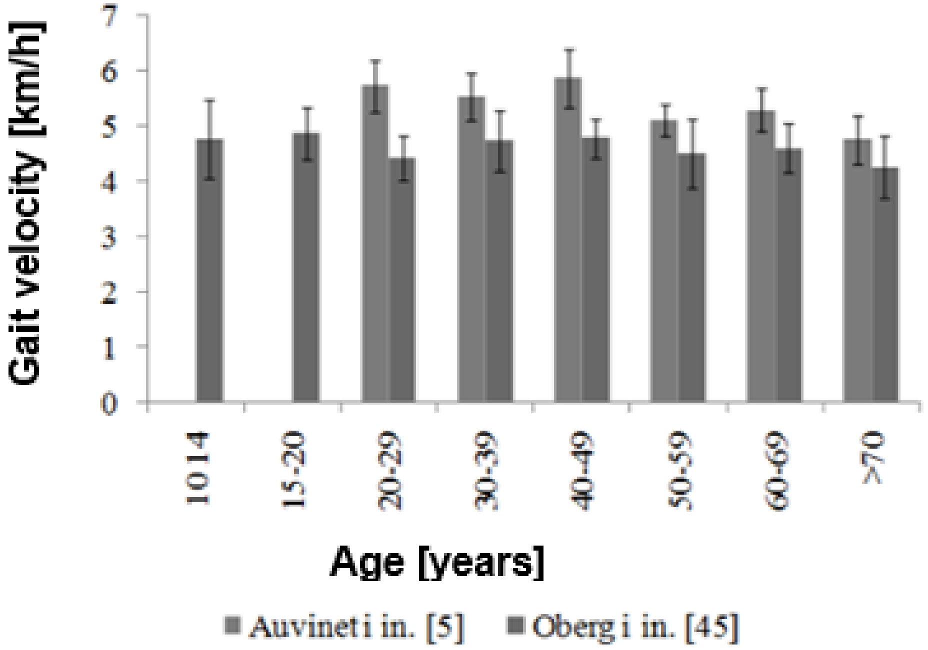
Cadence according to various studies with division into women and men

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS



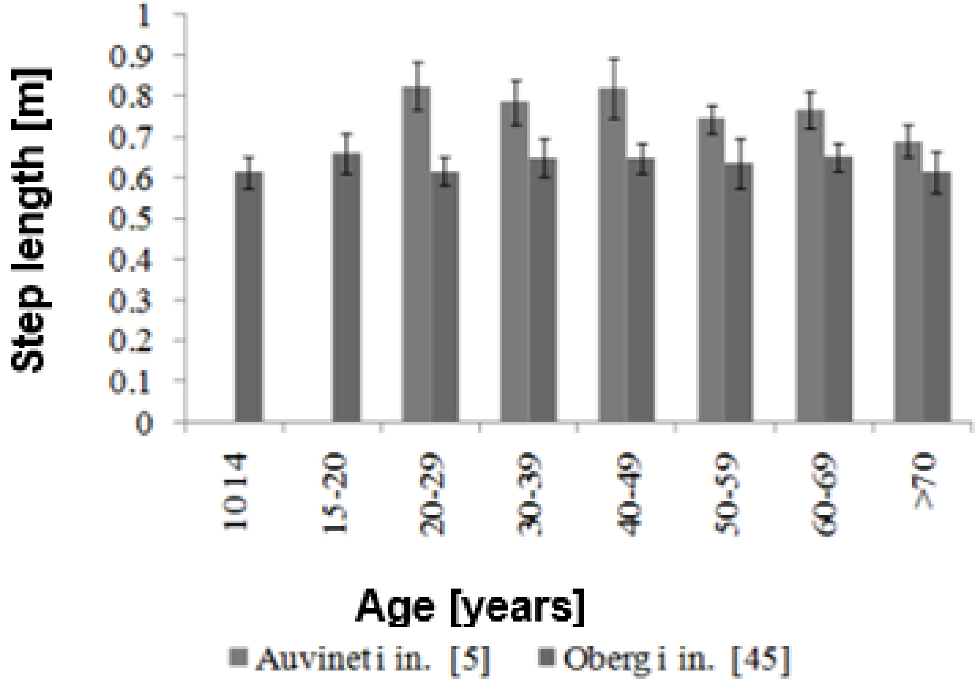
Step length according to various studies with division into women and men

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS



Walking speed in different age categories according to different authors

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS



Step length in different age categories according to different authors

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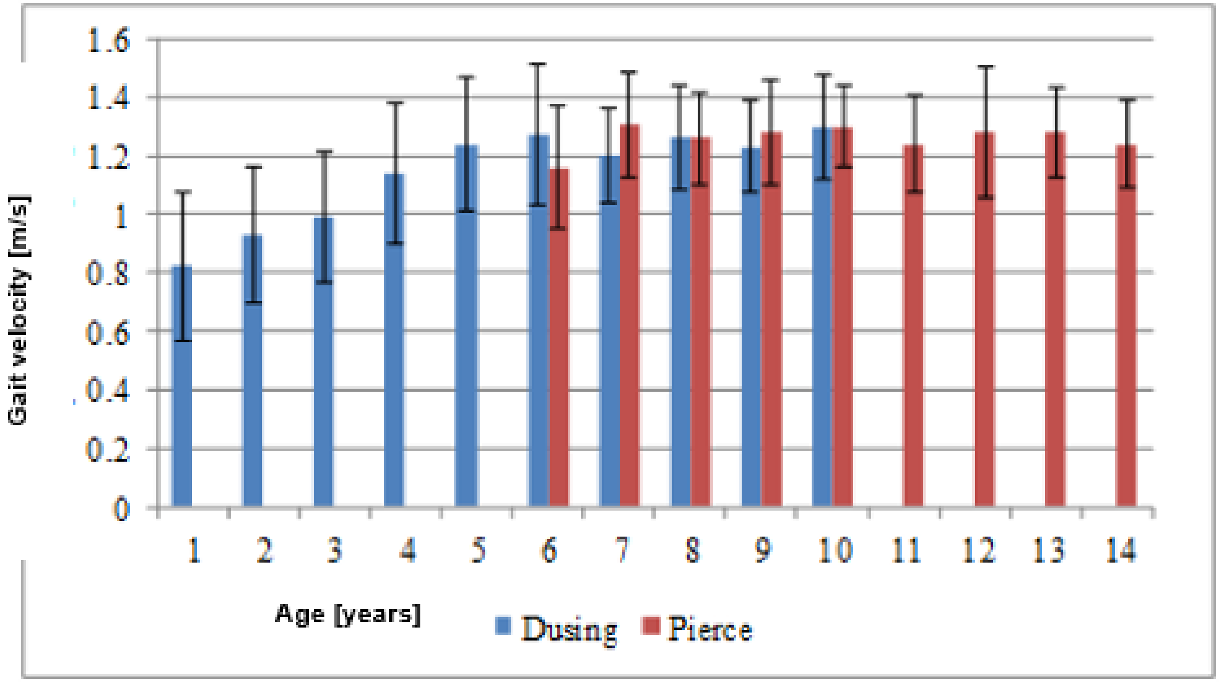
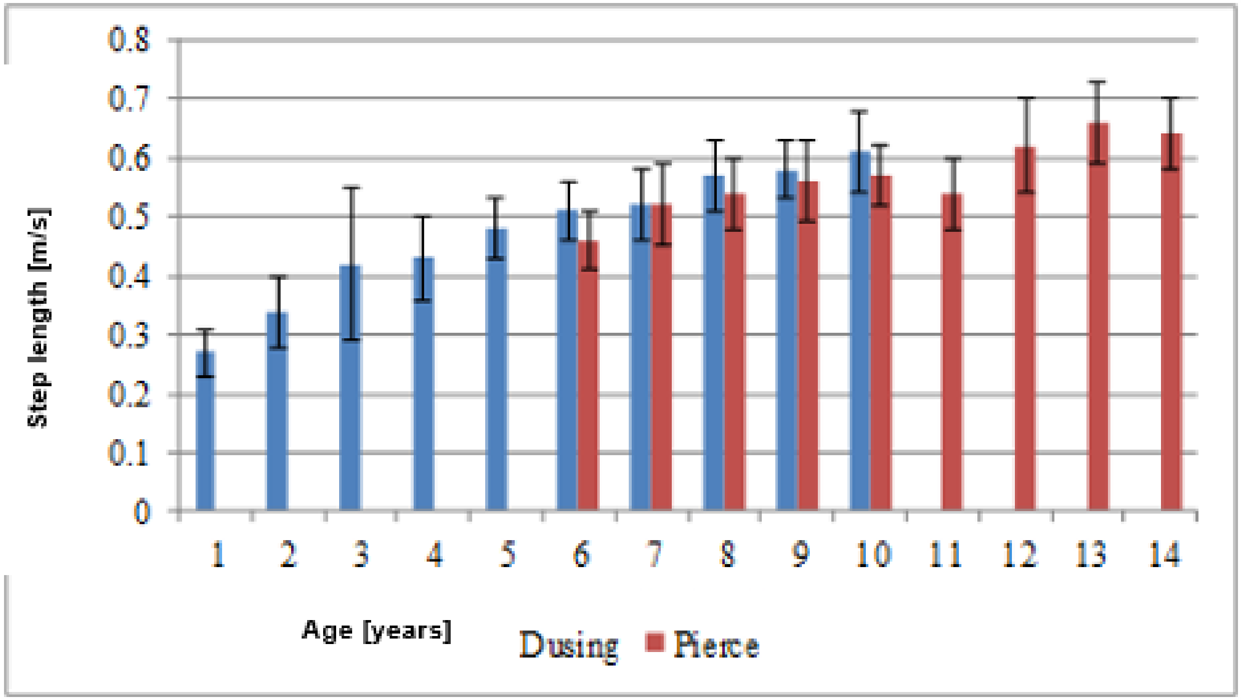


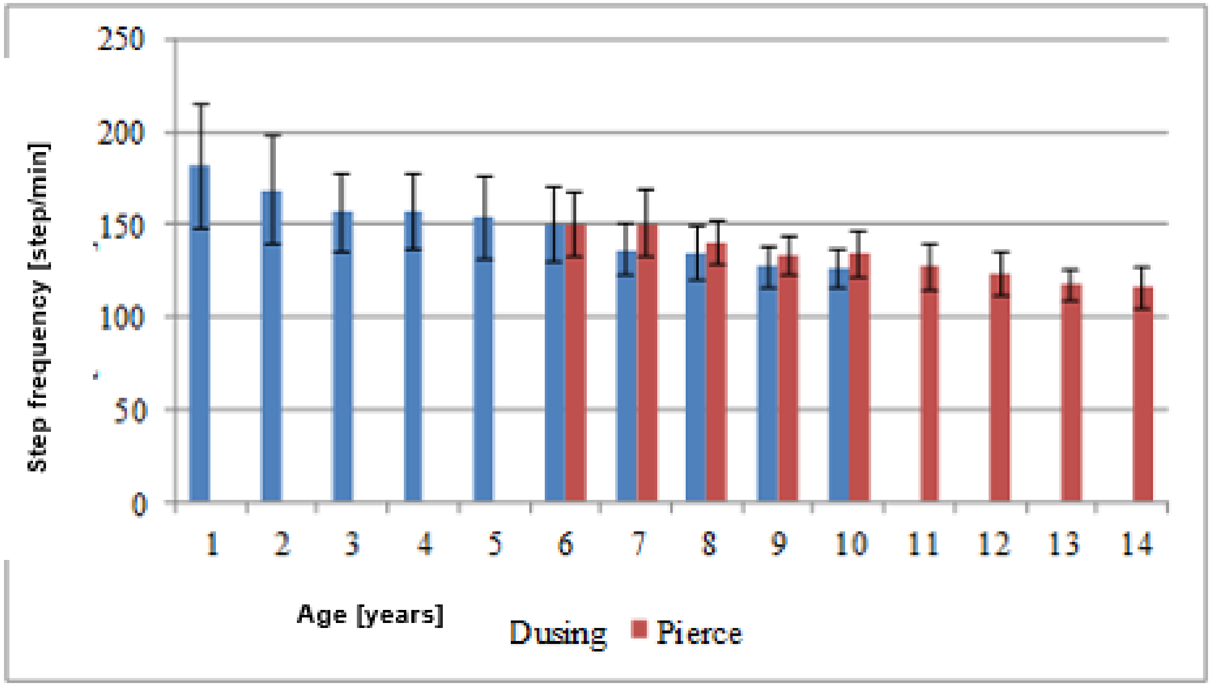
Walking speed of children of different ages

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS



Step length of children of different ages

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS



Cadence of children of different ages

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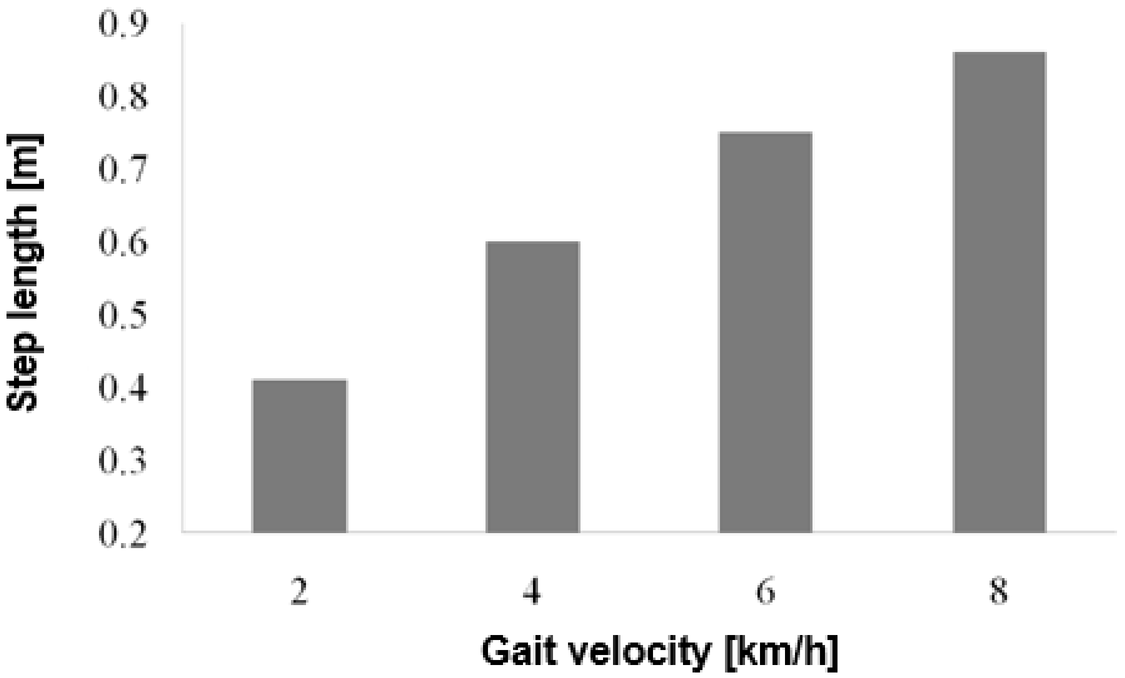
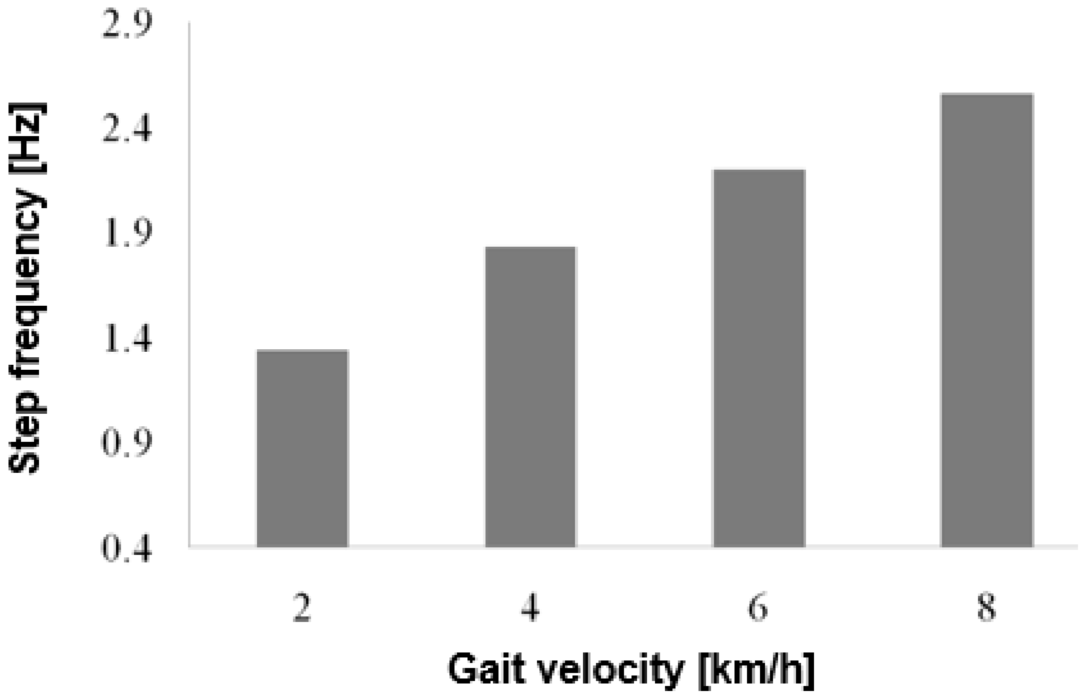


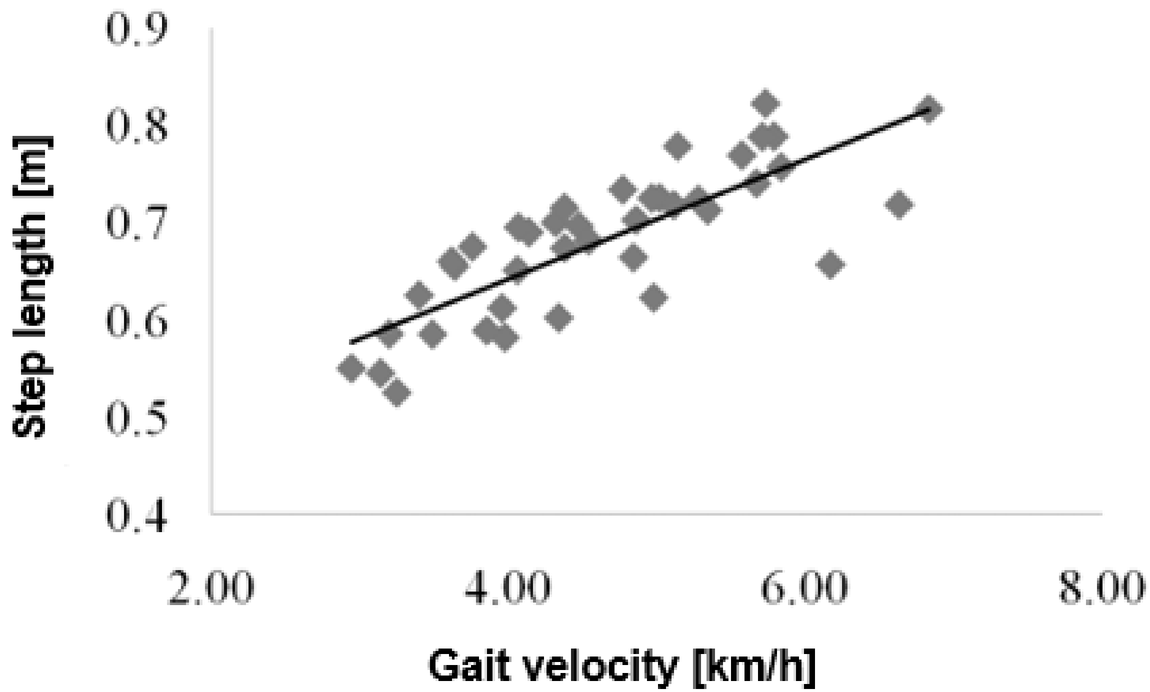
Changes in the length of the steps depending on the walking speed

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS



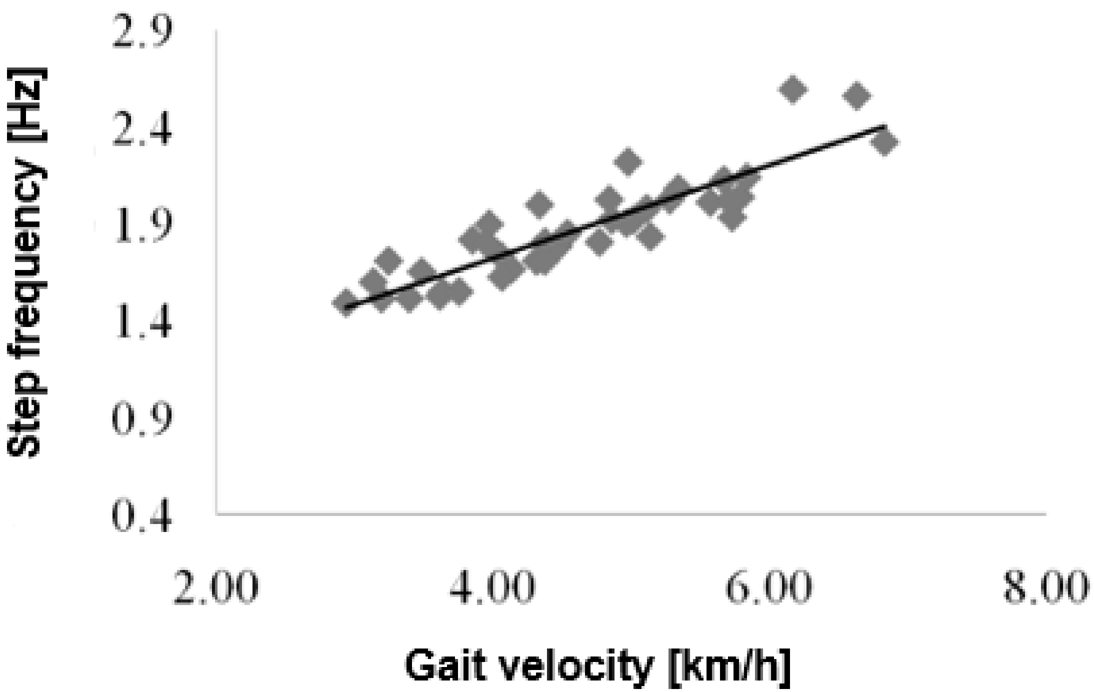
Changes in the cacence depending on the walking speed

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS



The relationship between the walking speed of healthy people and step length

TIME-SPACE PARAMETERS DESCRIBING GAIT BIOMECHANICS



The relationship between the walking speed of healthy people and cadence

KINEMATIC QUANTITIES DESCRIBING GAIT BIOMECHANICS - JOINT ANGLES

KINEMATIC QUANTITIES DESCRIBING GAIT BIOMECHANICS - JOINT ANGLES

Next parameters describing gait biomechanics are kinematic parameters. The courses of individual joint angles are most often analyzed, however, it is also possible to determine the trajectories of selected body points as well as linear and angular velocities and accelerations.

The analysis of joint angles consists in determining the course of individual anatomical angles in the joints (usually the lower limb) and angles describing the position of the pelvis. The determined values of angles and their waveforms in time are then referred to the standard waveforms obtained for healthy people.

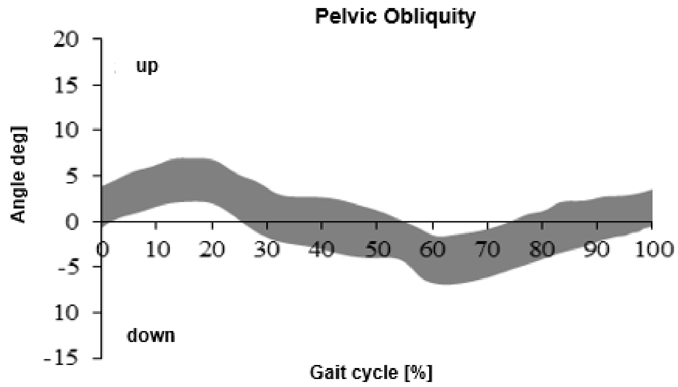
KINEMATIC QUANTITIES DESCRIBING GAIT BIOMECHANICS - JOINT ANGLES

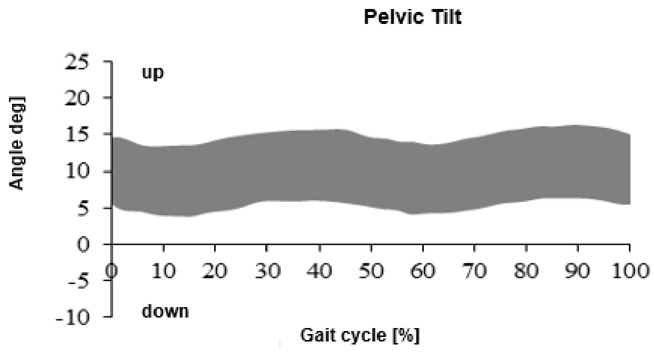
The analysis is usually performed for the following angles:

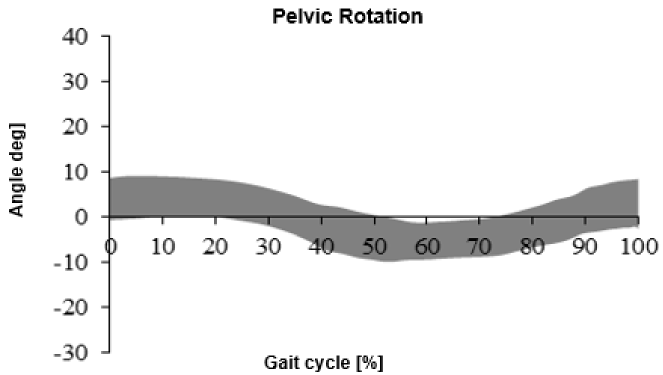
- in the case of the pelvis, these are pelvic tilt in the sagittal plane, lateral movements of the pelvis in the frontal plane (obliquity), and pelvic rotation in the transverse plane
- for the hip joint, these are the angles of flexion and extension in the sagittal plane, abduction and adduction in the frontal plane, and rotation around the vertical axis
- flexion and extension of the knee in the sagittal plane
- dorsal flexion and plantar flexion of the foot in the ankle and foot position in the frontal plane

KINEMATIC QUANTITIES DESCRIBING GAIT BIOMECHANICS - JOINT ANGLES

Pelvic angle

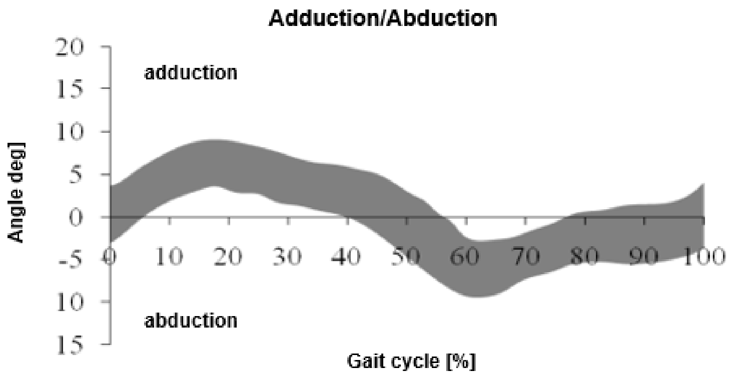


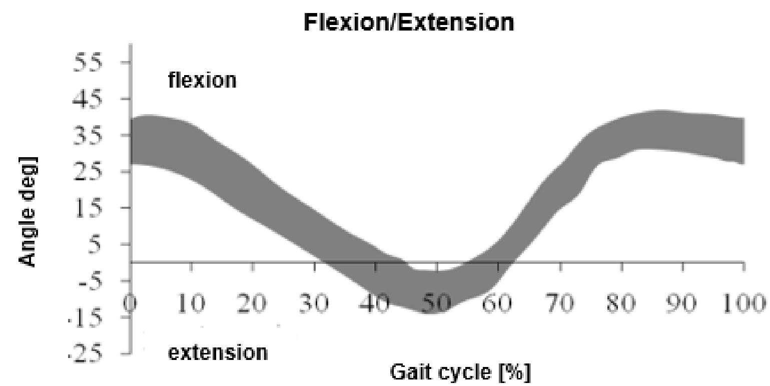


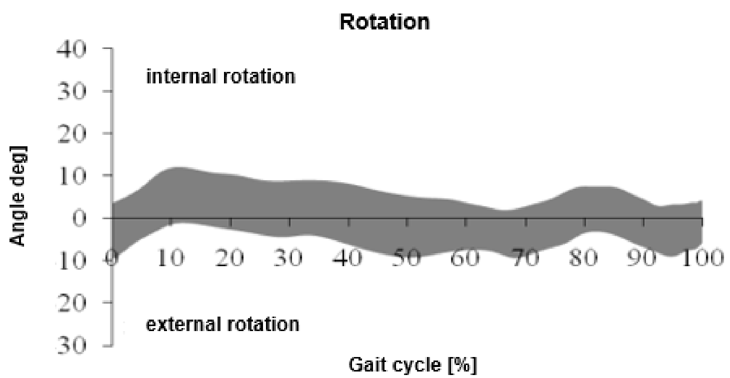


KINEMATIC QUANTITIES DESCRIBING GAIT BIOMECHANICS - JOINT ANGLES

Hip angle

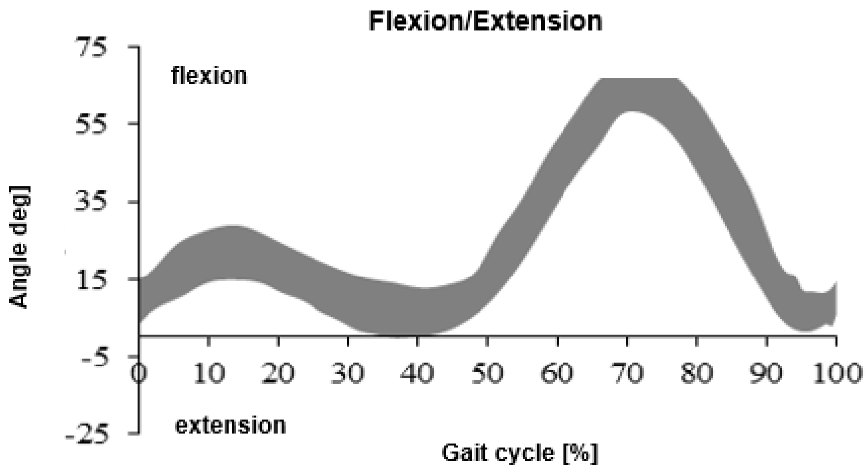


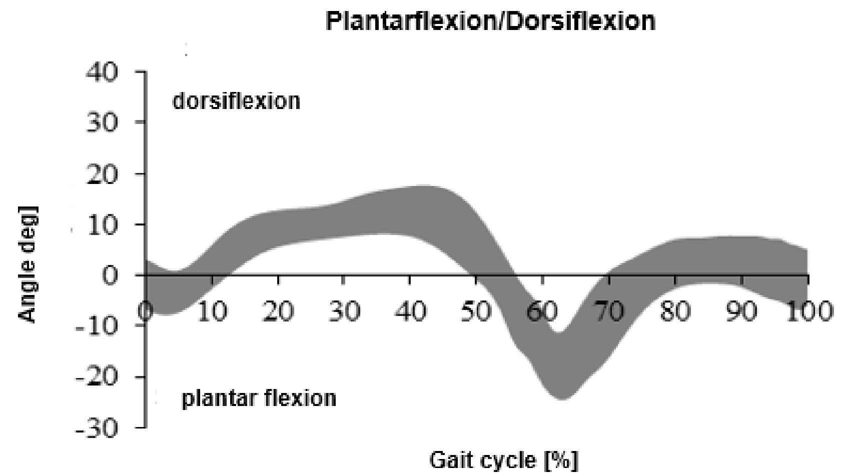




KINEMATIC QUANTITIES DESCRIBING GAIT BIOMECHANICS - JOINT ANGLES

Knee and ankle angel





DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT - GROUND REACTIONS

DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT - GROUND REACTIONS

Gait is a dynamic activity in which the whole body is propelled and kept in balance by skeletal muscles that generate forces that affect the human skeleton. In addition to muscular forces, the body is also influenced by forces such as gravity, inertia and ground reactions. The measurement of the latter is an important element of the analysis and description of gait biomechanics

DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT - GROUND REACTIONS

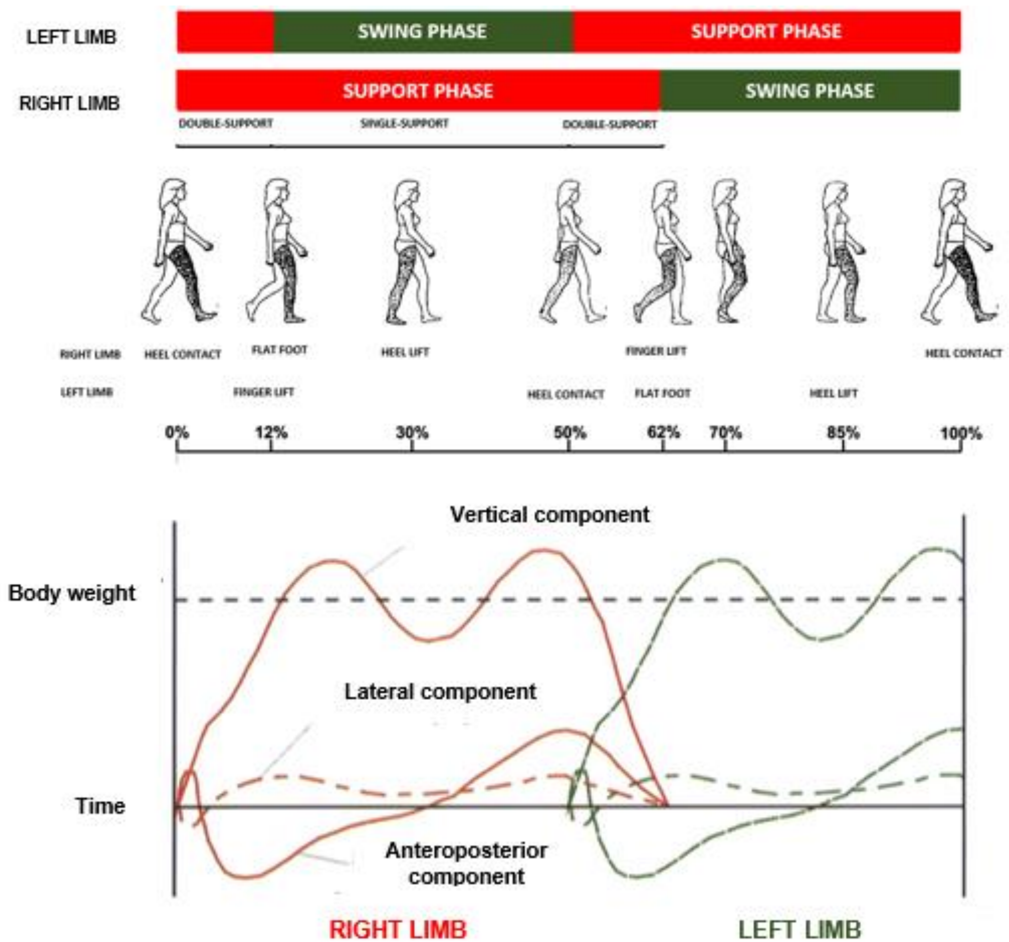
Ground reactions are forces that affect a human body (when walking they affect on feet) as a response to body pressure on this ground, according to Newton's 3rd law of dynamics, which says that if one body affects the other, the other affects the first with the same force in value and direction, but with the opposite sense.

DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT - GROUND REACTIONS

In the biomechanical description of gait, three ground reactions most often occur, which are actually three components of the ground reaction distributed over three forces parallel to the three axes of the coordinate system. These three components are:

- **vertical reaction** parallel to the vertical axis of the coordinate system,
- **anteroposterior reaction** parallel to the horizontal axis of the coordinate system determined in accordance with the gait direction of the test person,
- **lateral (transverse) reaction** parallel to the horizontal axis of the coordinate system traced in a direction perpendicular to the walking direction of the test person.

DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT - GROUND REACTIONS



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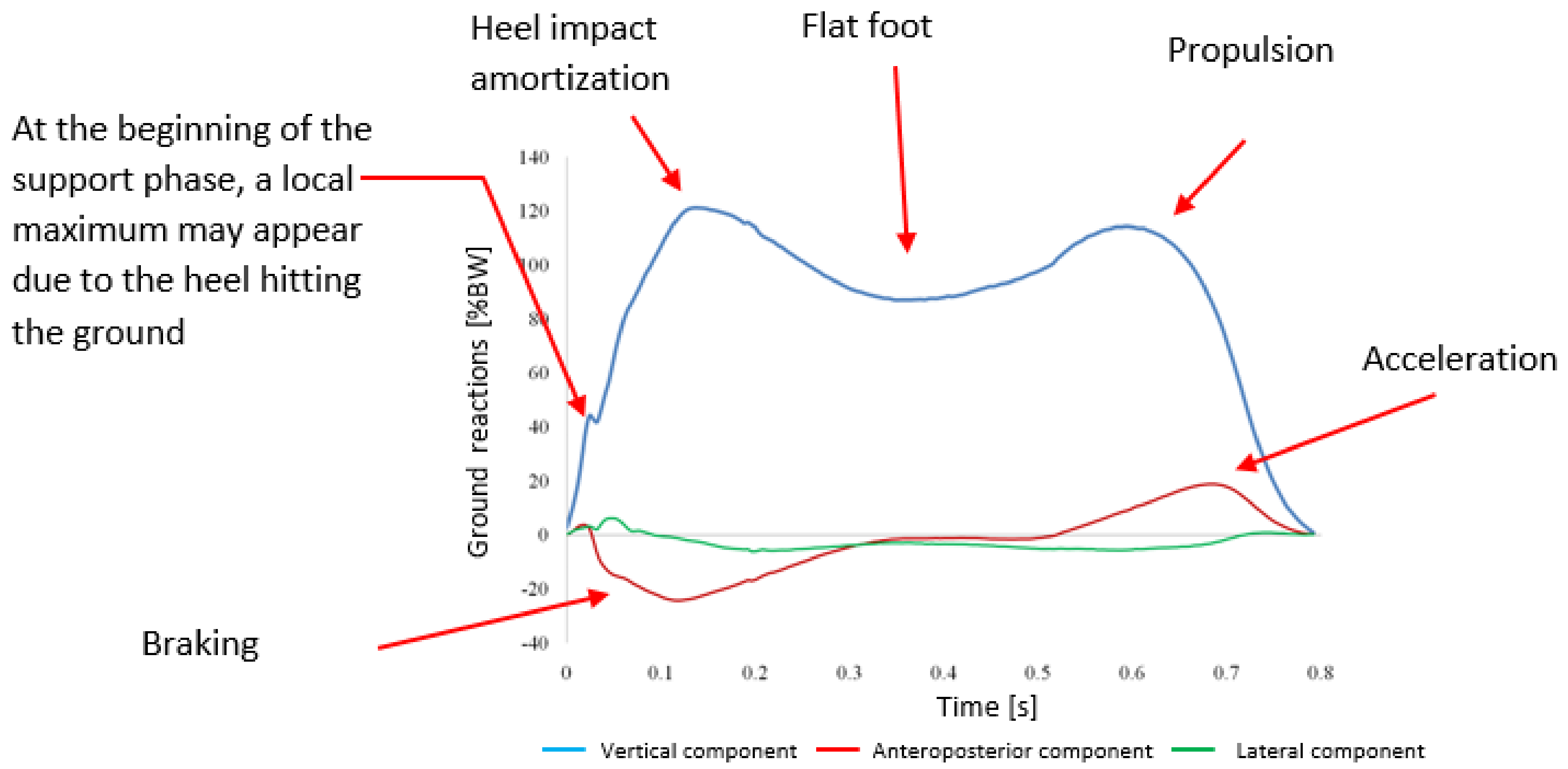

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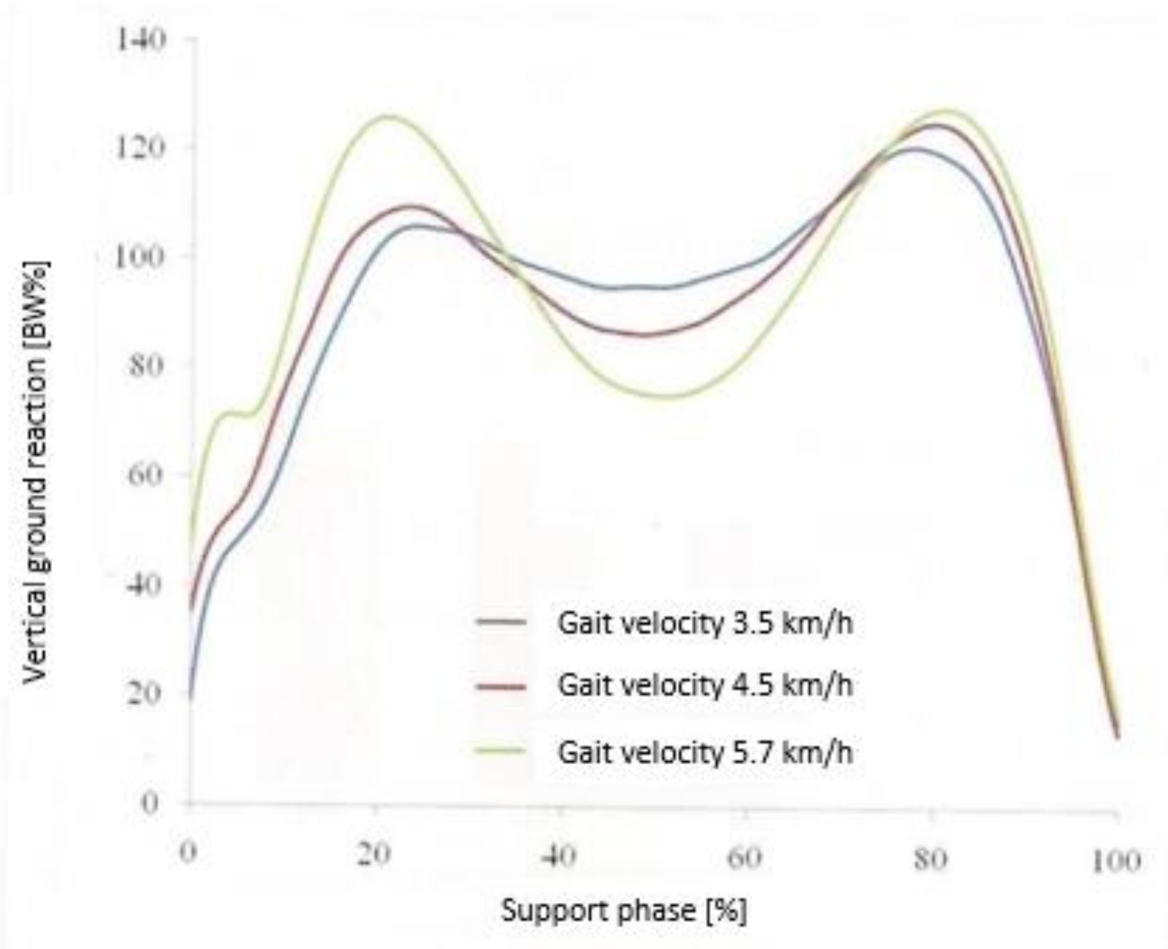

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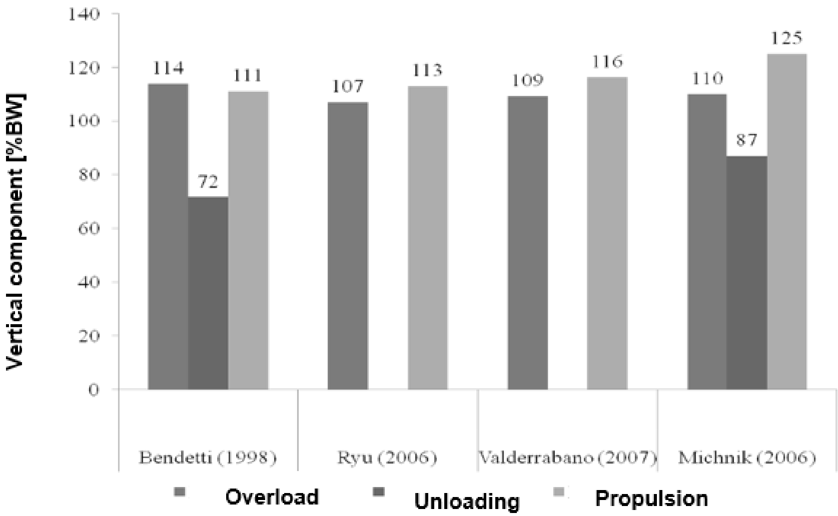
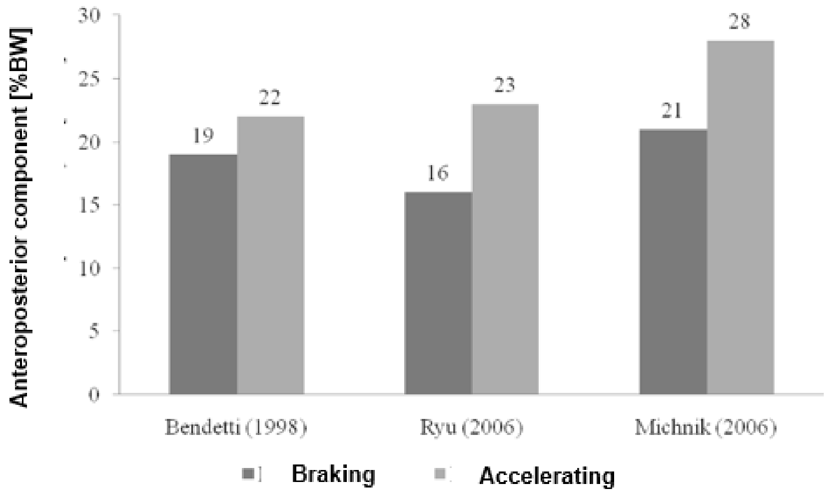




DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT - GROUND REACTIONS

By conducting quantitative analysis of gait biomechanics on the basis of ground reaction, certain values are determined that describe the correctness or gait or may indicate deviations from the norm. Each of the presented parameters, except for those referring to the double-support phase, are determined separately for the right and left limbs.

DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT - GROUND REACTIONS

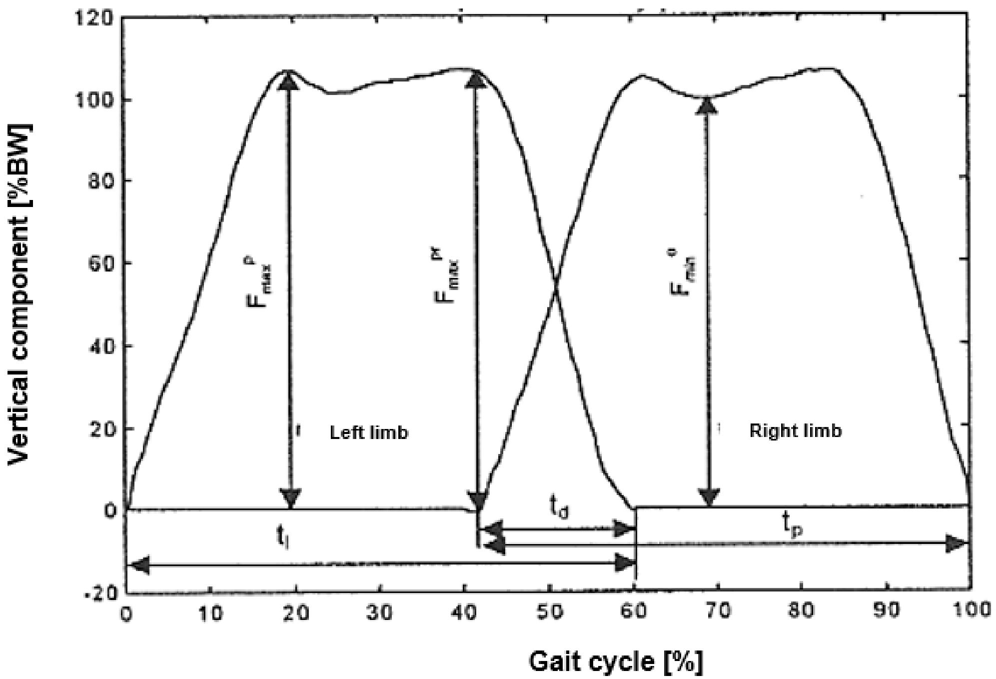
t_l, t_p – contact time of the left and right foot with the ground

t_d – duration of the double-support phase,

F_{max}^{p} – maximum of the overload phase,

F_{min}^{o} – minimum of the unloading phase,

F_{max}^{pr} – maximum of the propulsive phase

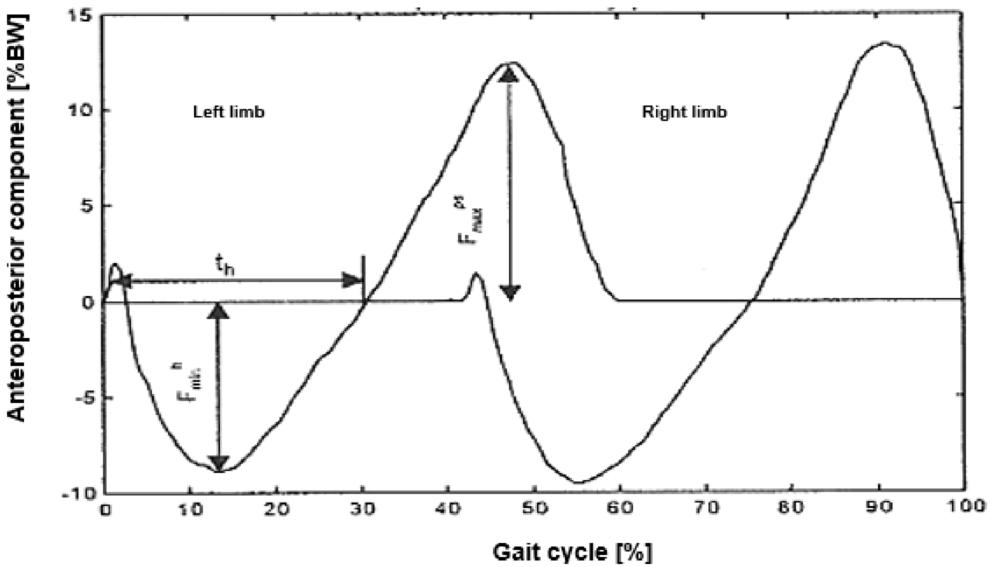


DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT - GROUND REACTIONS

t_h – braking time

F_{min}^{h} – minimum of the braking phase

F_{max}^{ps} – maximum of the acceleration phase

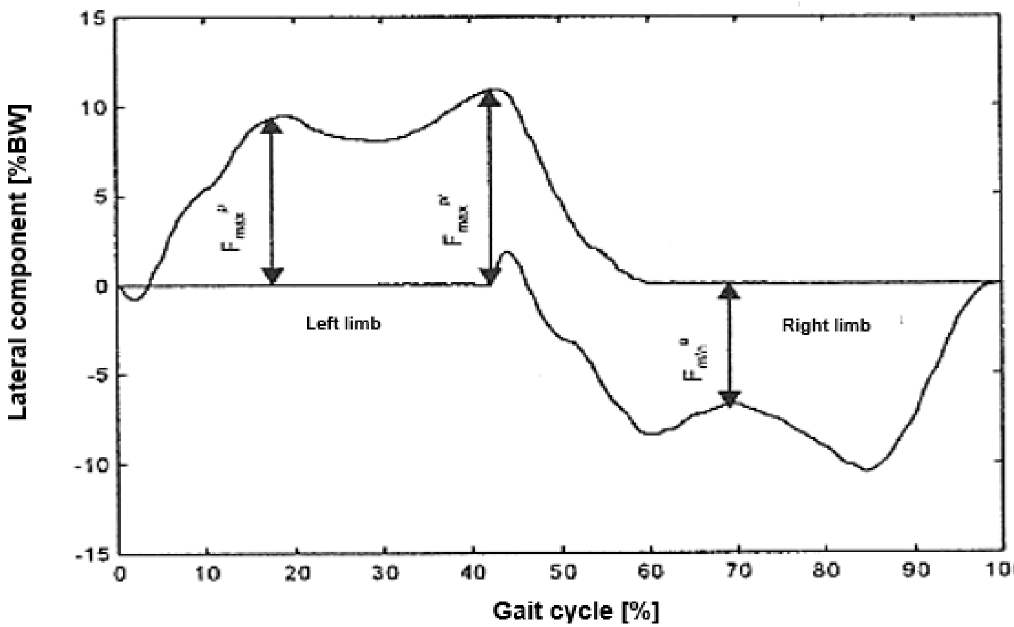


DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT - GROUND REACTIONS

F_{max}^{p} – maximum of the overload phase,

F_{min}^{o} – minimum of the unloading phase,

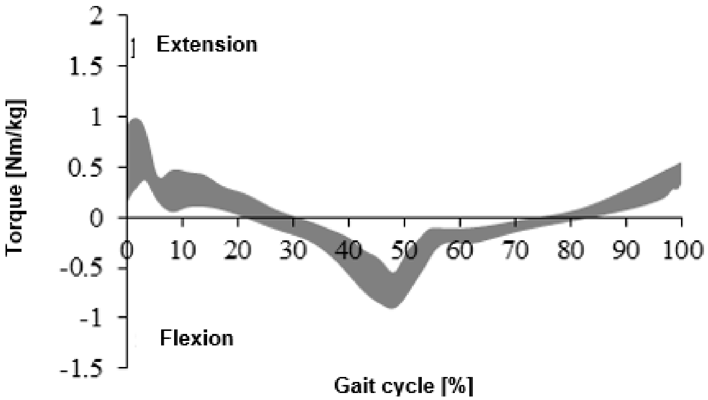
F_{max}^{pr} – maximum of the propulsive phase

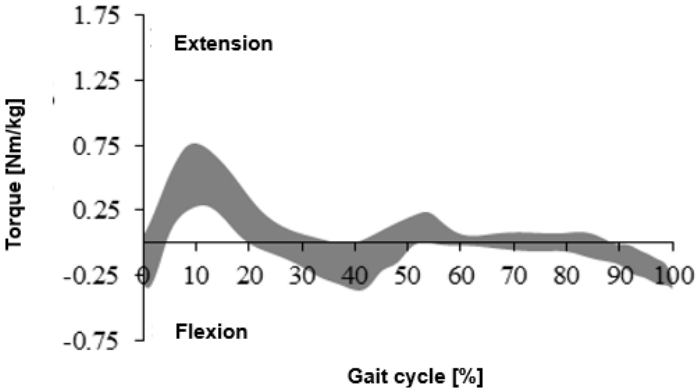


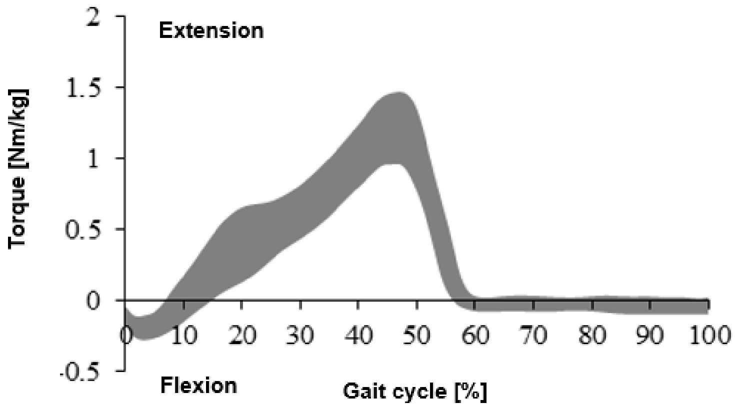
OTHER DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT

OTHER DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT

Moments of muscle forces in the joints

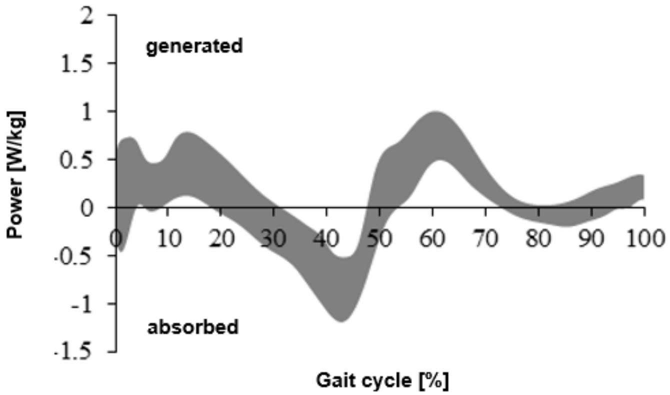


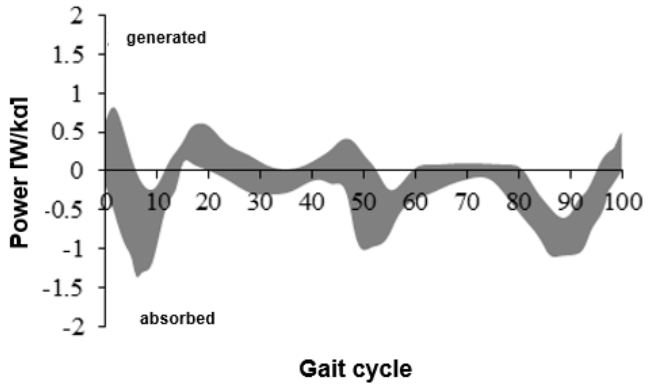


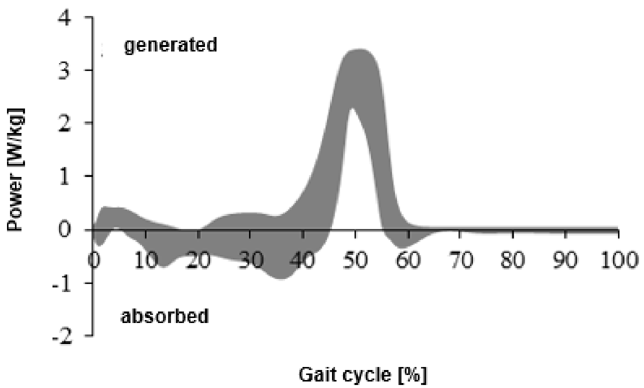


OTHER DYNAMIC QUANTITIES DESCRIBING BIOMECHANICS OF GAIT

Power in joints







MUSCLE WORK DURING WALKING

MUSCLE WORK DURING WALKING

To determine muscle work during gait, surface EMG is most commonly used. The potential difference between two electrodes located along the muscle fibers is obtained directly as the result of the measurement. The measured potential difference results from the fact of appearing and movement of action potential. Due to the method of measurement consisting in sticking electrodes to the skin, it is possible to collectively measure the electrical activity of the entire muscle or muscles group

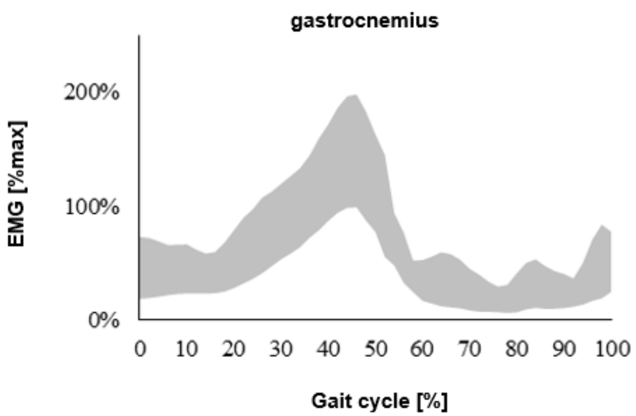
MUSCLE WORK DURING WALKING

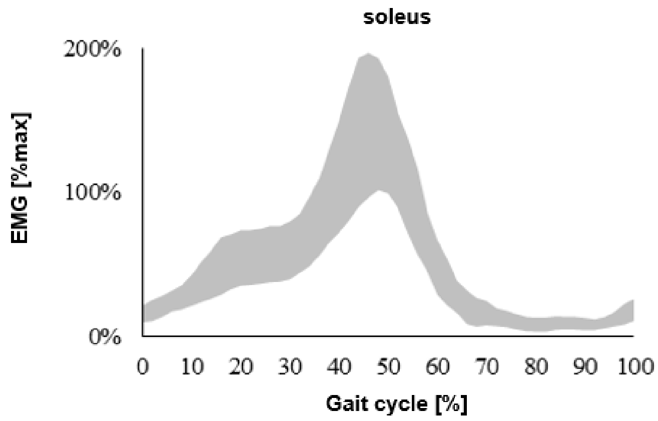
During walking, EMG measurement is usually performed for the following muscles:

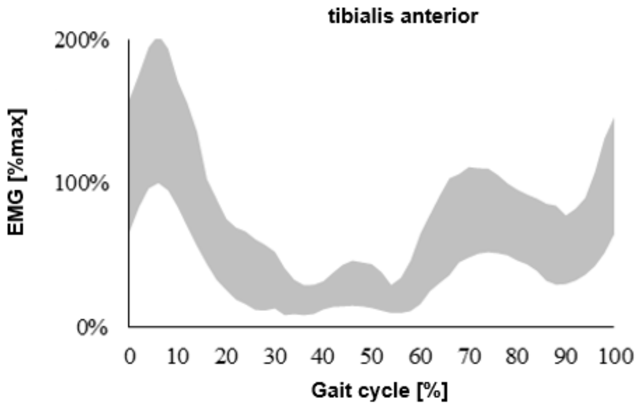
- anterior tibial muscle,
- gastrocnemius muscle,
- soleus muscle,
- rectus femoris muscle,
- vastus femoris muscle,
- gluteus maximus muscle.

MUSCLE WORK DURING WALKING

Praca mięśni w obrębie stawu skokowego

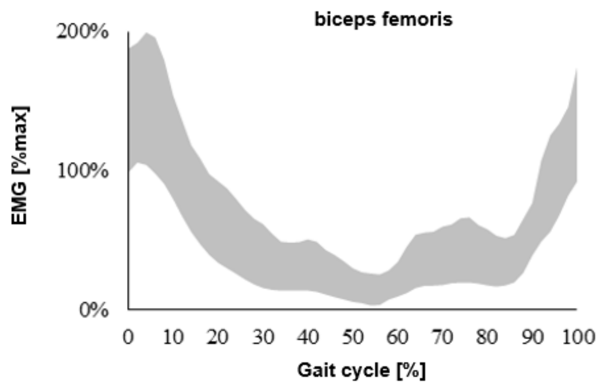


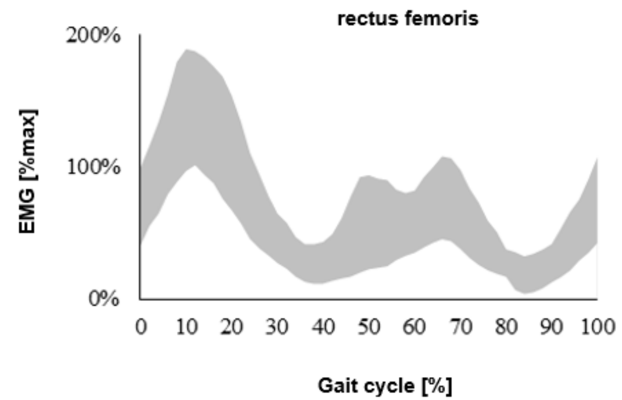


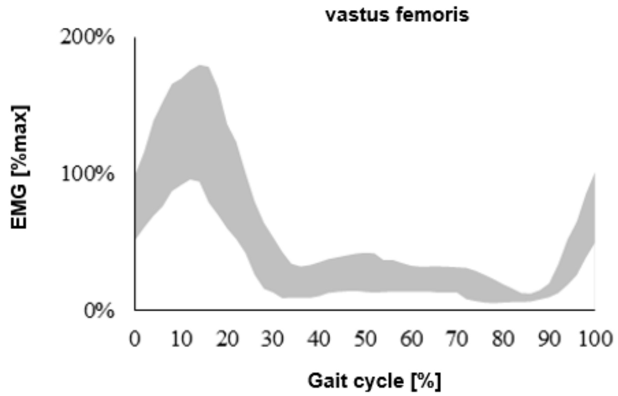


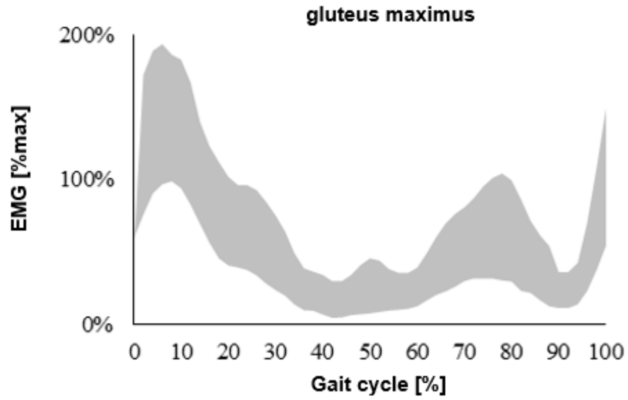
MUSCLE WORK DURING WALKING

Praca mięśni w obrębie stawu biodrowego i kolanowego









MUSCLE WORK DURING WALKING

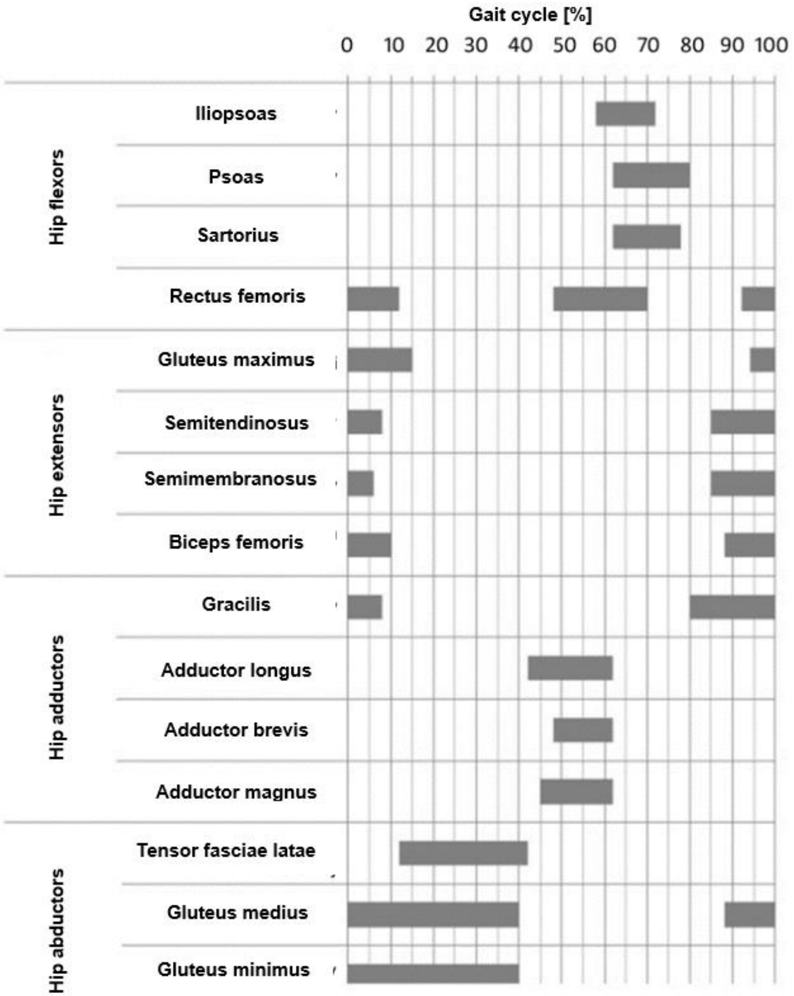
Another way of analysing muscle work is on / off analysis, i.e. determining when a given muscle starts working and when it ends, i.e. in what phase of the movement the muscle is active. A healthy muscle under normal working conditions only turns on when necessary and turns off when its work becomes unnecessary.

MUSCLE WORK DURING WALKING

Detection of muscle activity in the movement phase when in case of healthy person this muscle does not work, may indicate some abnormalities, such as, for example, pain, increased tension (e.g. due to spasticity), joint instability or it can result from stress or poor motor coordination. Improper muscle work may also indicate the existence of compensatory. This information can be very important, enabling the patient to be properly diagnosed and then treated

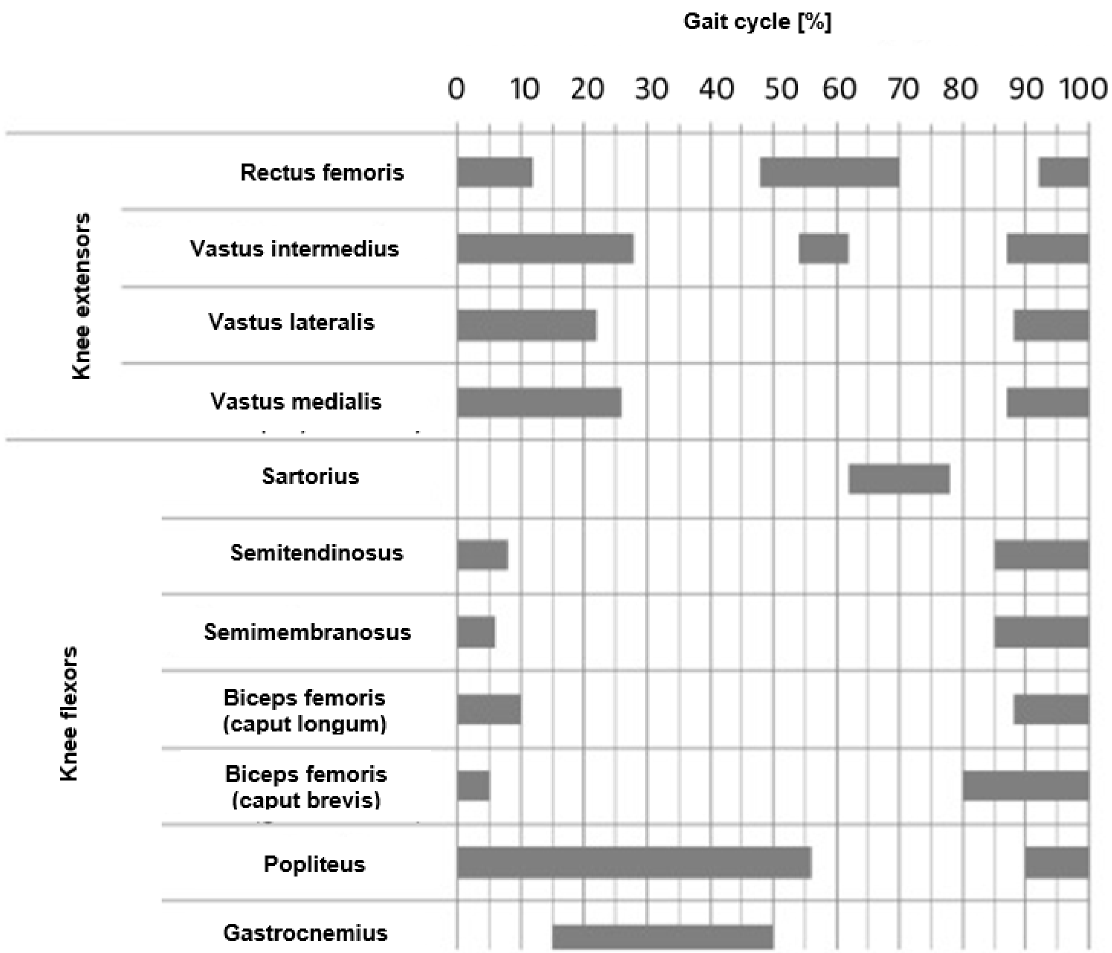
MUSCLE WORK DURING WALKING

Muscle activity in the hip joint during the normal gait cycle



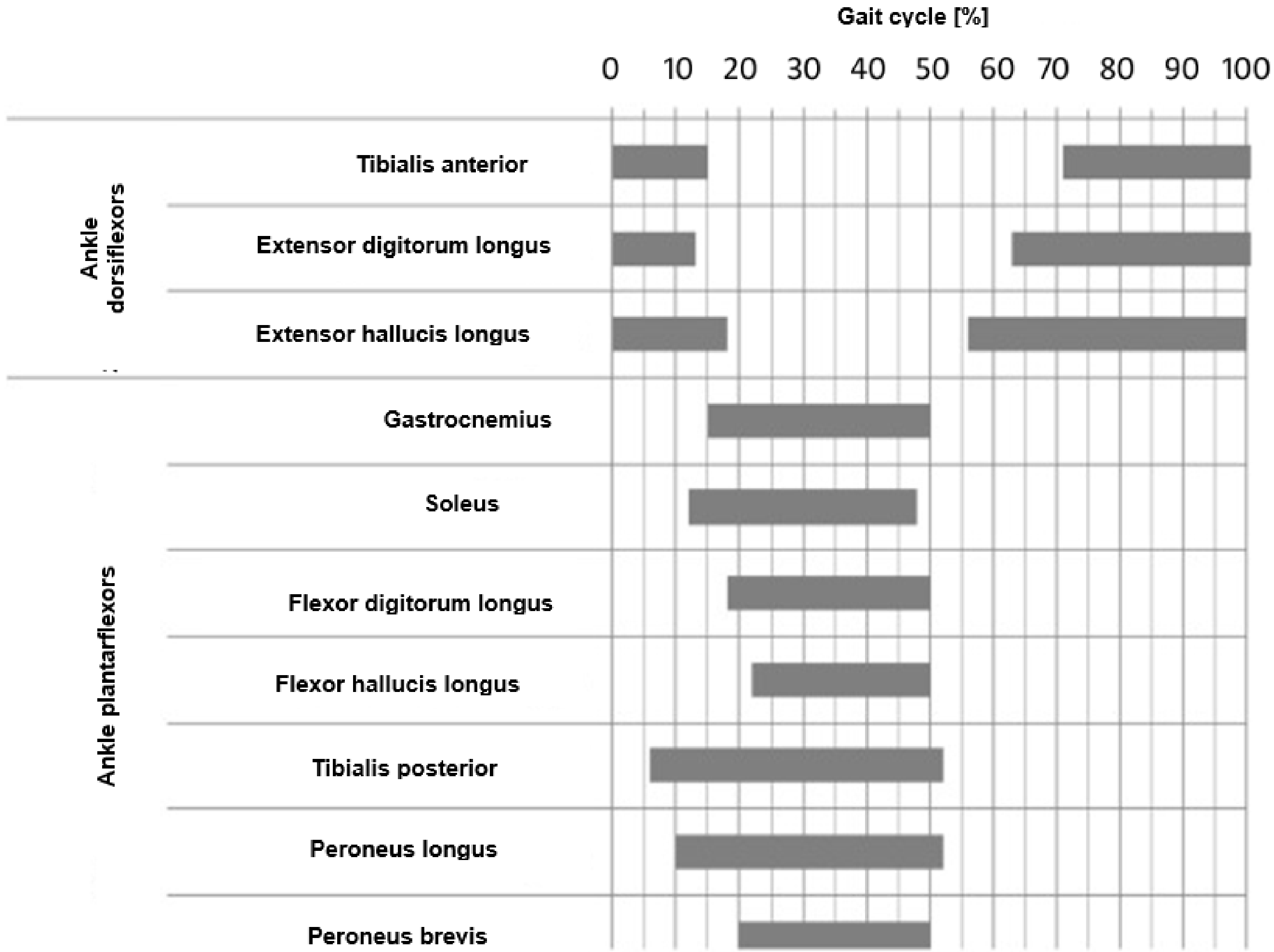
MUSCLE WORK DURING WALKING

Muscle activity in the knee joint during the normal gait cycle



MUSCLE WORK DURING WALKING

Muscle activity in the ankle joint during the normal gait cycle



KEY IDEAS

KEY IDEAS

- Knowledge of gait biomechanics is necessary to evaluate the human musculoskeletal system.
- For the description of gait biomechanics, parameters obtained from observation and measurements done by means of specialized equipment are used.
- When assessing gait, one should simultaneously base on determined kinematic and dynamic values as well as on measurements of muscle functions. Only the use of all these elements gives a full picture of biomechanics of gait, which in turn enables the correct assessment of possible disorders.

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