Tutorial: Human gait analysis

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In this tutorial you are going to learn about human gait, and how to analyze this. The focus in this tutorial is on muscle function and the role of push-off in human gait. A full example data set is available, including video, kinematic and kinetic data, and electromyography (EMG) of muscle activation patterns. To analyze these data you will need to install the freeware MoXieViewer and BodyMech, which can be downloaded from the website.

To start up

a. Install MoXie-viewer from www.smalll.nl: http://www.smalll.nl/VUMC/REV/MoXie/Downloads.htm
b. Install BodyMech by copying and unzipping mfiles from the *BodyMech3.06.01_DW.zip* file to disk and add directory (with subfolders) to Matlab path using *File → Set path*
c. Download and unzip gait data *Gait Analysis Data.zip*

Available data

- 6 trials: normal speed; slow; very slow; very very slow; fast and 'asimo' imitation
- Muscle activity (EMG) of the right leg, of 6 muscles (see figure in additional information)
- Ground reaction forces of right and left leg of one stride per trial
- 3D kinematics and kinetics of trunk, pelvis, right and left upper and lower legs and feet

Assignment 1. 'Passive dynamic' walking

a. Open 'MWI_03_normal.mox' in moxie-viewer; Study video, full speed and frame by frame.
b. Study muscle activity graphs: what phases in walking would you consider 'passive dynamic'?
c. Compare EMG graphs with normal values from the literature: do you see differences? (use *reference EMG* panel)
d. Open mox files for various walking speeds: what are the main changes in muscle activity with speed? (Tip: compare *time-normalized* average EMG graphs)
   What are differences in ground reaction force?
e. Identify bi-articular muscles. When are those muscles active in normal walking at comfortable speed? What could be their role?

Assignment 2. Push-off

a. Open 'BodyMech' in matlab (type in 'BodyMech' in command window). Load MWI_03_normal.bmb file (via Load BMB file)
b. Study the gait trial in 'view'; 'orthogonal views', (mark: 'Stick figures' and 'External Reaction Force'). Identify how the ground reaction force vectors act around the ankle, knee and hip joints. How does this relate to the joint moments? Compare with actual joint moments using 'GraphJointMoments' command.
c. Load the BODY structure in the MATLAB command window ('global BODY'; 'BODY') and look at what's available in the structure (see attachment)
d. Plot sagittal ankle joint moment versus ankle joint angle (see BodyMech tips & tricks). Does the ankle act like a spring?
e. When is the ankle joint generating / dissipating energy?
f. Does power generation change with walking speed? Does the ankle always deliver net positive work?

Assignment 3. Extra questions

a. Open mox file for 'asimo walking': what are the main differences in gait pattern between normal and asimo walking? What are the main differences in muscle activity and ground reaction force? Can you explain why these changes occurred? Is this a good imitation of asimo robot walking?
b. How do ankle moment and power generation change in 'asimo walking'?
c. In normal gait, can you identify a pre-emptive push-off?
d. Can you relate power generation to muscle function?

Assignment 4. Philosophical questions

a. How passive dynamic is human walking?
b. What would be the ideal ankle actuation system for biped robots or prostheses?
c. What can we learn about human walking from passive dynamic walkers, and what can we learn from human walking to optimize dynamic walkers?

Some related papers – not at all complete

- Hansen, A. H., Childress, D. S., Miff, S. C., Gard, S. A., Mesplay, K. P., (2004). The human ankle during walking: implications for design of biomimetic ankle prostheses. J Biomech 37, 1467-1474.

- Van Ingen Schenau GJ, Bobbert MF, Rozendal RH (1987). The unique action of bi-articular muscles in complex movements. J Anat. 1987 Dec;155:1-5.

- Iida F, Rummel J, Seyfarth A. Bipedal walking and running with spring-like biarticular muscles. J Biomech. 2008;41(3):656-67.

- Neptune RR, Kautz SA, Zajac FE. Contributions of the individual ankle plantar flexors to support, forward progression and swing initiation during walking. J Biomech. 2001 Nov;34(11):1387-98.

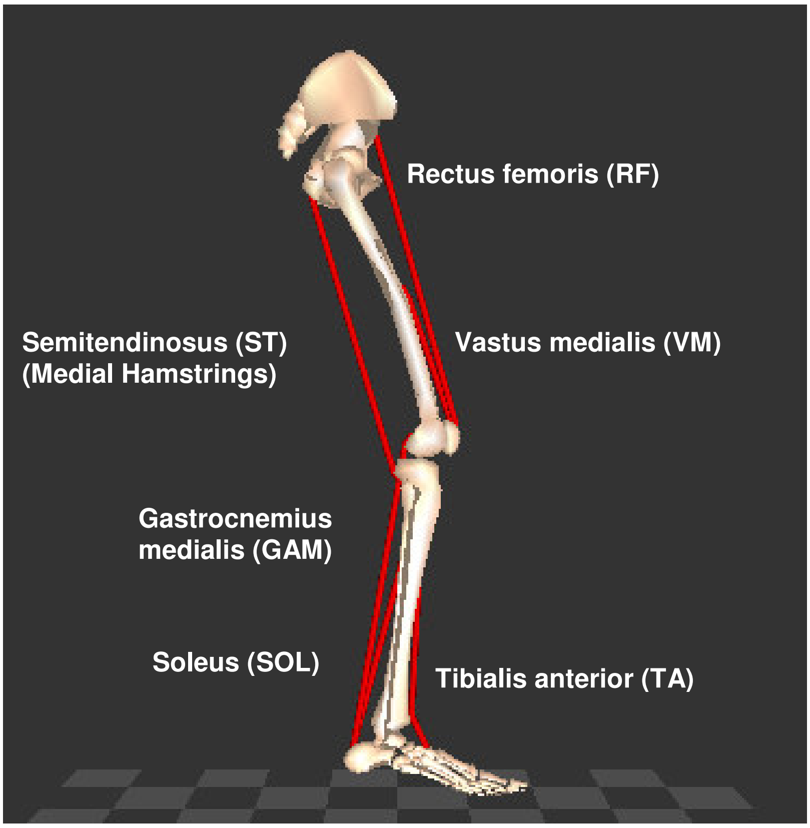
- Neptune RR, Sasaki K, Kautz SA. The effect of walking speed on muscle function and mechanical energetics. Gait Posture. 2007

- Schwartz, M.H. Rozumalski, A. and Trost, J.P. (2008). The effect of walking speed on the gait of typically developing children. J Biomech in press

- Zajac FE, Neptune RR, Kautz SA. Biomechanics and muscle coordination of human walking: Part I: introduction to concepts, power transfer, dynamics and simulations. Gait Posture. 2002 Dec;16(3):215-32. Review. Part II: lessons from dynamical simulations and clinical implications. Gait Posture. 2003 Feb;17(1):1-17. Review.

Additional information

Measured muscles



MoXieViewer Tips & Tricks

- You can rearrange the windows by dragging them, the next time you open the viewer the windows will appear as arranged.
- You can click in all windows to select a specific instant in the gait cycle
- You can select different trials with the ‘current folder’ panel (it may take some time to load the videos)
- With *cycle navigator* you can step between consecutive strides and compare steps at the same % of the gait cycle
- With *gait cycle* you can see different phases of the gait cycle and step through them
- With the buttons in the EMG and force panels you can turn on and off viewing of specific signals
- You can view EMG in μV or as % of max (lower left corner of EMG envelope window)
- Click with right mouse button in EMG or Force panel to scale the y-axes
- The *time normalized EMG graphs* give average EMG over all full steps (white lines) and values of current step (yellow).
- Open MoXieViewer twice or more to easily compare files
- Upper left corner: check out zoom graphs and goniometer / SAGAruler to estimate joint angles
- The lower left corner shows walking speed as recorded online

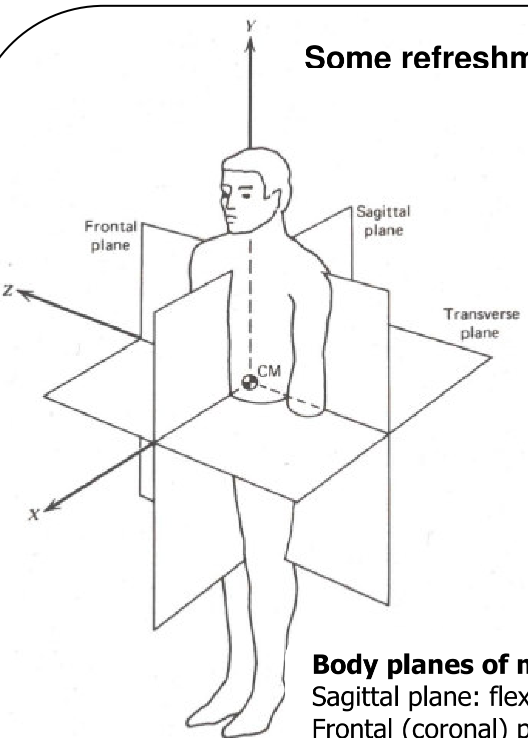
BodyMech info, tips & tricks

- Open BodyMech by typing ‘BodyMech’ in command window
- You can load a body through the BodyMech user interface (Load BMB file), or by typing ‘loadbodyfile’ in the command window. The segments, joints and muscles of the BODY are listed in the BodyMech window.
- Make the BODY global in the command window by typing ‘global BODY’; you can now see the BODY structure (see attachment BodyMech BODY Structure)
- All BODYs contain data of one and a half strides: from right leg initial contact (IC) to left leg initial contact of the next stride
- The coordinate system is defined with X pointing forward, Y pointing upwards and Z pointing to the right (of walking direction).

- **Joint angles** (`BODY.JOINT(i).PostureRefKinematics.RotationAngles)` are derived using ZXY decomposition, which means that:
  - 1st row = rotation about Z axis = flexion/extension
  - 2nd row = rotation about X axis = ab/adduction
  - 3rd row = rotation about Y axis = exo/endorotation
- Positive angles are defined using a right-hand coordinate system (looking from X direction, rotation from Y to Z is positive, etc)

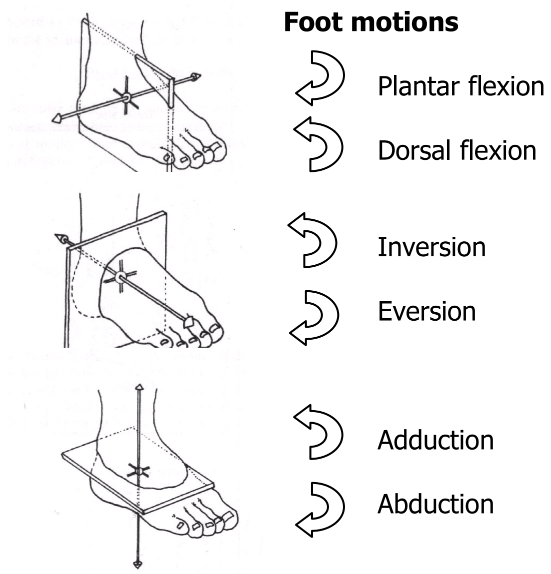
- **Joint moments** (`BODY.JOINT(i).Kinetics.NetMoment`) are defined as XYZ:
  - 1st row = rotation about X axis = ab/adduction
  - 2nd row = rotation about Y axis = exo/endorotation
  - 3rd row = rotation about Z axis = flexion/extension
- The command ‘GraphJointMoments’ plots all joint moments, and shows what is defined as positive or negative
- All moments are *internal* net joint moments, i.e. the summed moments of all muscles, ligaments, friction/damping etc. around that joint
- Joint moments have been calculated so that extension, abduction and exorotation are always positive

Some refreshments



Body planes of motion
Sagittal plane: flexion / extension
Frontal (coronal) plane: ab/adduction
Transverse plane – Exo/endorotation

Foot motions



BODY structure