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This presentation will begin shortly...

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The AnyBody Modeling System™

- Full-body musculoskeletal simulations for activities of daily living
- Muscle and joint force computation + many other features
- Unprecedented model detail and validity

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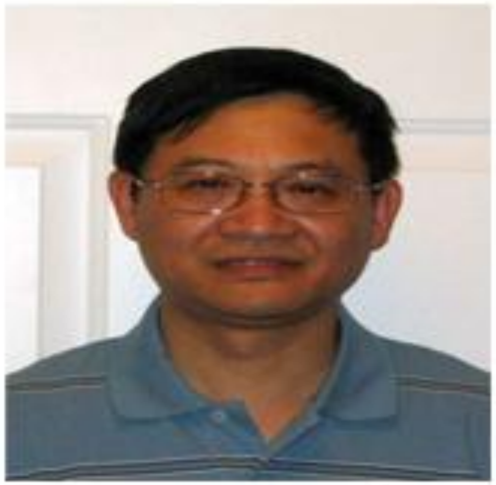
Today's webcast presentation: Workplace Ergonomics - Stilt Walking

Presenter



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Analysis of Musculoskeletal Loading in Low Extremities for Stilts Walking

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Presenter: John Z. Wu

CDC

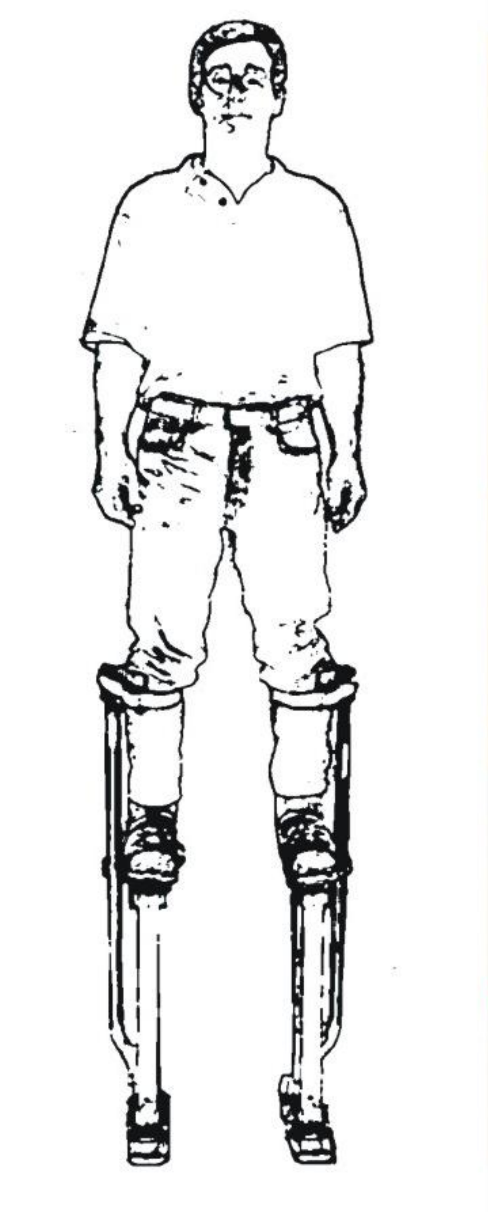
NIOSH

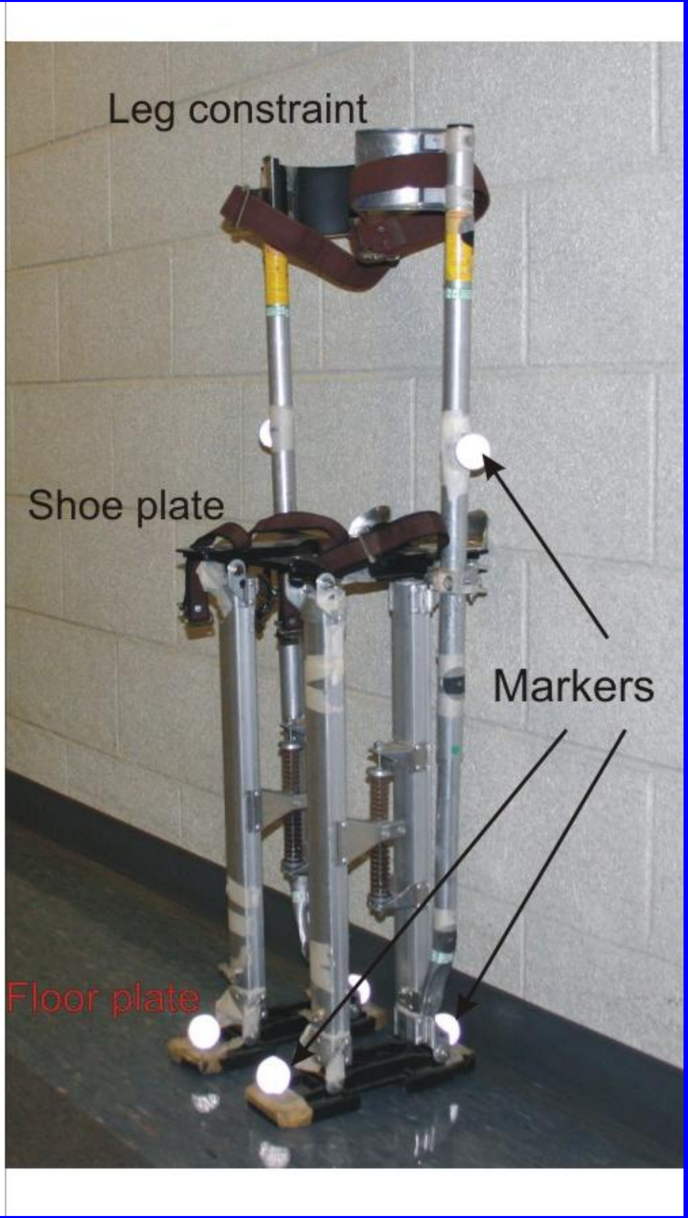
Background

- Stilts are commonly used at construction sites for many tasks, such as taping and sanding on the ceiling or upper half of a wall.

- It is not clear whether the use of stilts during walking increases musculoskeletal loading.

Typical stilts used in construction





Background

- It is hypothesized that the use of stilts may place workers at increased risk for knee injuries or may increase the likelihood of trips and falls.

  (e.g., *Schneider and Susi, 1994*)

- The state of California and the province of Ontario (Canada) have, therefore, established legislation against the use of stilts as a preventive measure for occupational safety.

Hypothesis

Due to the increased height and possibly faster walking speed, the postural stability in stilts walking will be more likely influenced by visual or psychological perturbations at work sites compared with the normal walking.

The stilts add excessive mass moments of inertia to the lower limbs, requiring the stilt users to apply more effort during walking.

The use of stilts in walking will increase the joint moments and muscle loadings in the lower limbs.

Objective

- To develop an inverse dynamic model of stilts walking to investigate their effects on joint moments and musculoskeletal loadings in the lower limbs

Method: model

- **Stilts-walking model was developed using AnyBody (version 3.0)**
- **Existing three-dimensional gait model** *(Gait3D)* **was adapted and modified**
- **Only the lower body is included (two legs and pelvis)**

Method: human model

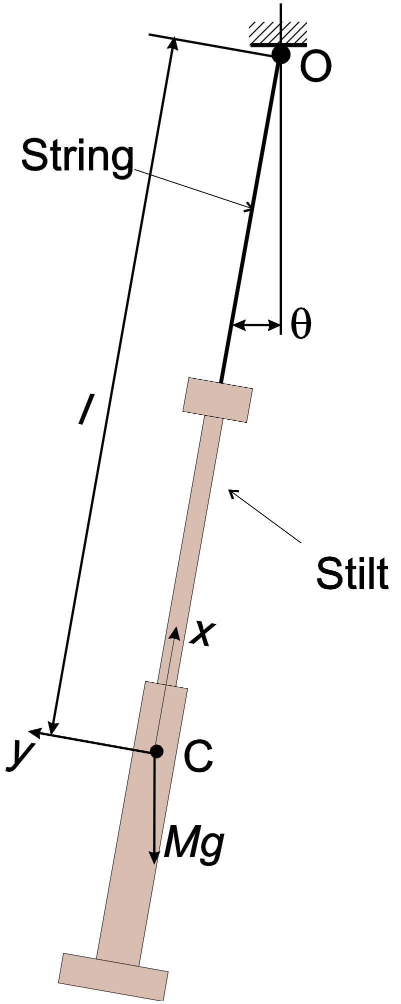
- Hip joints: 3 DOFs
  - external/internal rotation
  - abduction/adduction
  - extension/flexion
- Knee joints: 1 DOF
  - extension/flexion
- Ankle joints: 2 DOFs
  - plantar/dosi flexsion
  - inversion/eversion
- Each leg includes 35 muscles

Method: stilts model

- **One piece, no joint**

- **Mechanical properties:**
  - Mass : 3.64 kg each
  - Total height: 1.02 m
  - CoM: 0.41 m from bottom
  - Mass moment of inertia in three directions were determined experimentally

Tests of mass moment of inertia of the stilts



$$\ddot{\theta}_z + \omega_z^2 \theta_z = 0$$

$$\omega_z = \sqrt{\frac{Mgl}{I_{oZ}}}, \qquad I_{oZ} = I_{CZ} + Ml^2$$

$$I_{CZ} = \frac{Mgl}{\omega_z^2} - Ml^2$$

$$I_{CY} = \frac{Mgl}{\omega_y^2} - Ml^2$$

$$I_{CX} = \frac{1}{2} Mr^2$$

Stilts mechanical properties

$Icx = 0.02\ kg/m^2$

$Icy = 0.95\ kg/m^2$

$Icz = 1.27\ kg/m^2$

Stilts 3D meshes were drawn using *SolidWorks* and included into AnyBody

Method: human subject tests

- Four healthy construction workers
  - Age: 35.8 (+/- 7.7) years
  - Height: 1.77 (+/- 0.03) m
  - Body mass: 79.5 (+/- 16.4) kg

- Subjects walked without or with stilts through a 12-meter straight path

- When walking on the stilts, the subjects were elevated by 0.61 m from the floor.

Method: data collection

- A total of 18 reflective spherical markers were placed on the lower extremities of the subjects, at anatomical landmarks, as suggested by Vaughan et al. (1999). For the tests with stilts walking, three additional motion markers were placed on each stilt.
- The marker kinematics were collected at 60 Hz using a six-camera *Peak Motus Motion* Measurement System
- Two force platforms embedded in the walkway were used to measure ground reaction forces at a frequency of 600 Hz.

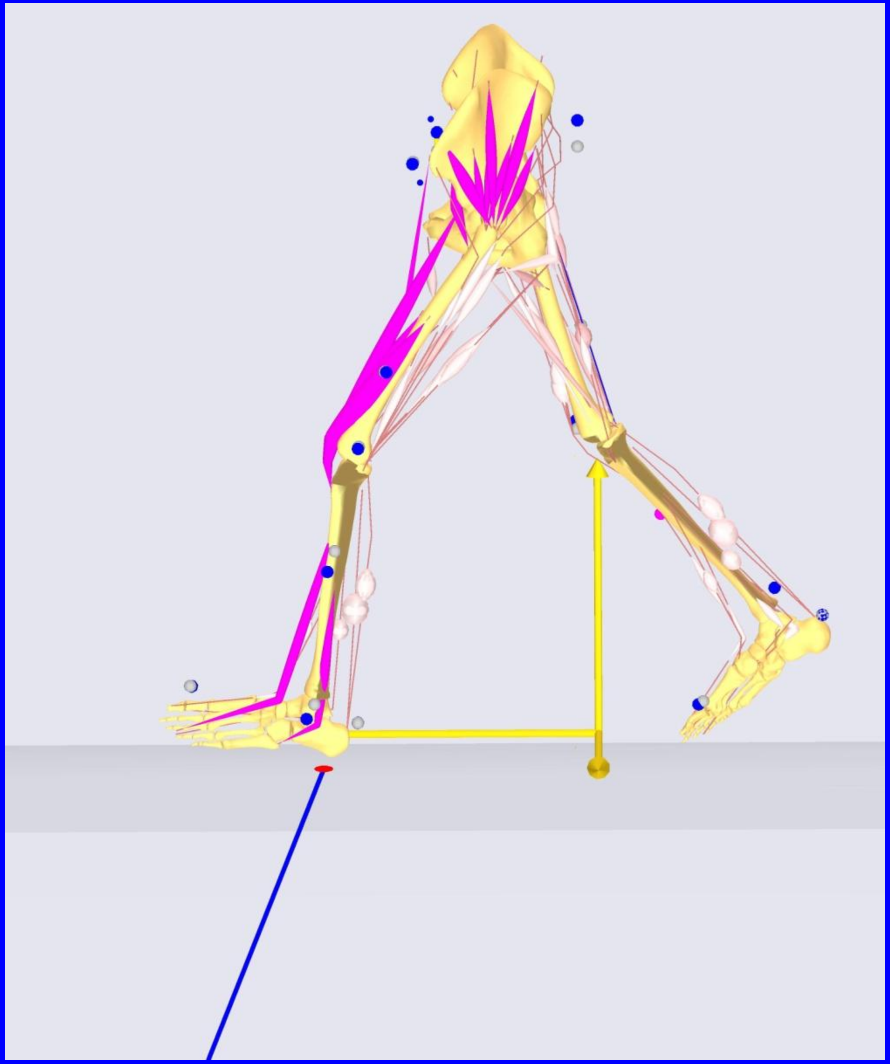
Attachment of stilts to human legs

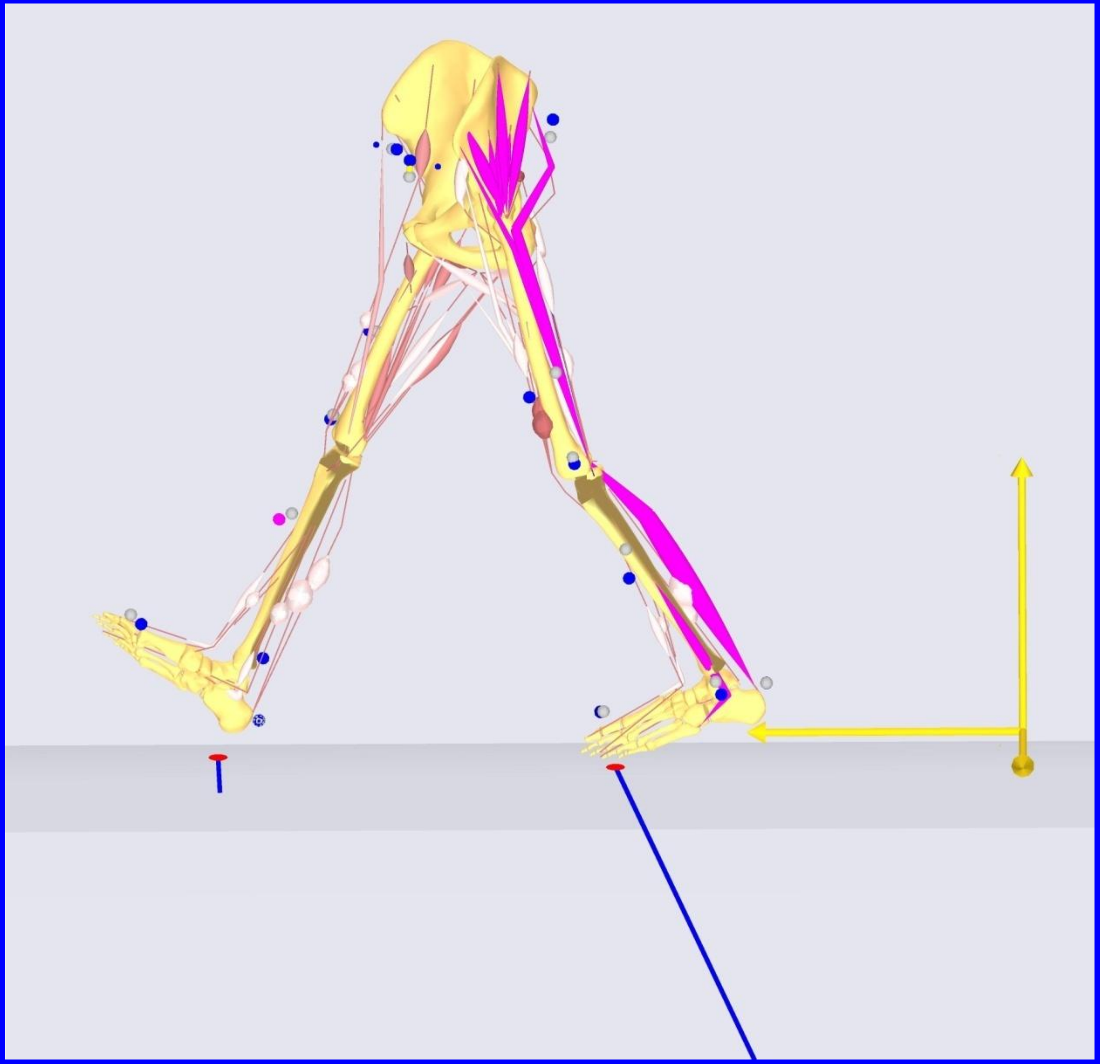
- ❖ Feet constrained to the foot plates at all three directions using *“AnyReactionForce”*

- ❖ Knee connected to the stilts via using springs using *“AnyForce”*

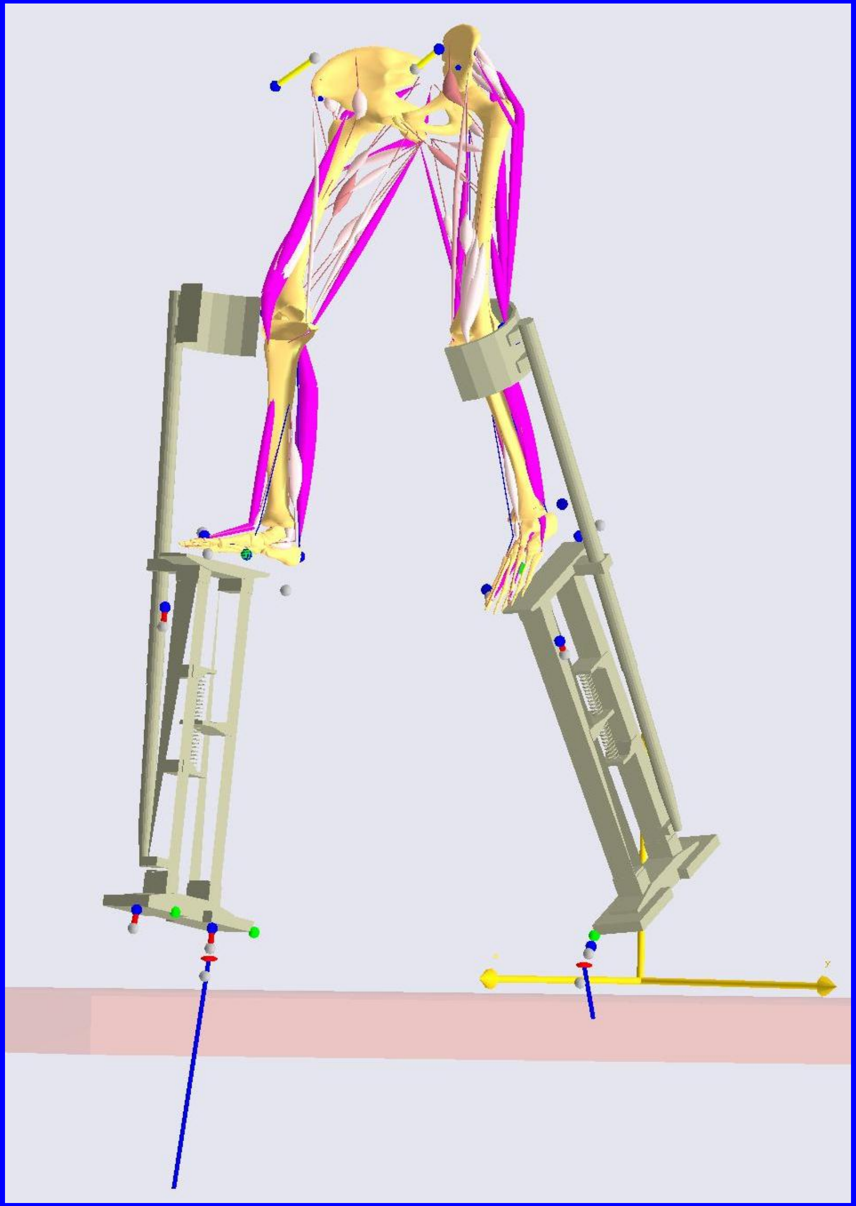
- ❖ Force plates will be interacted with stilts instead of human feet

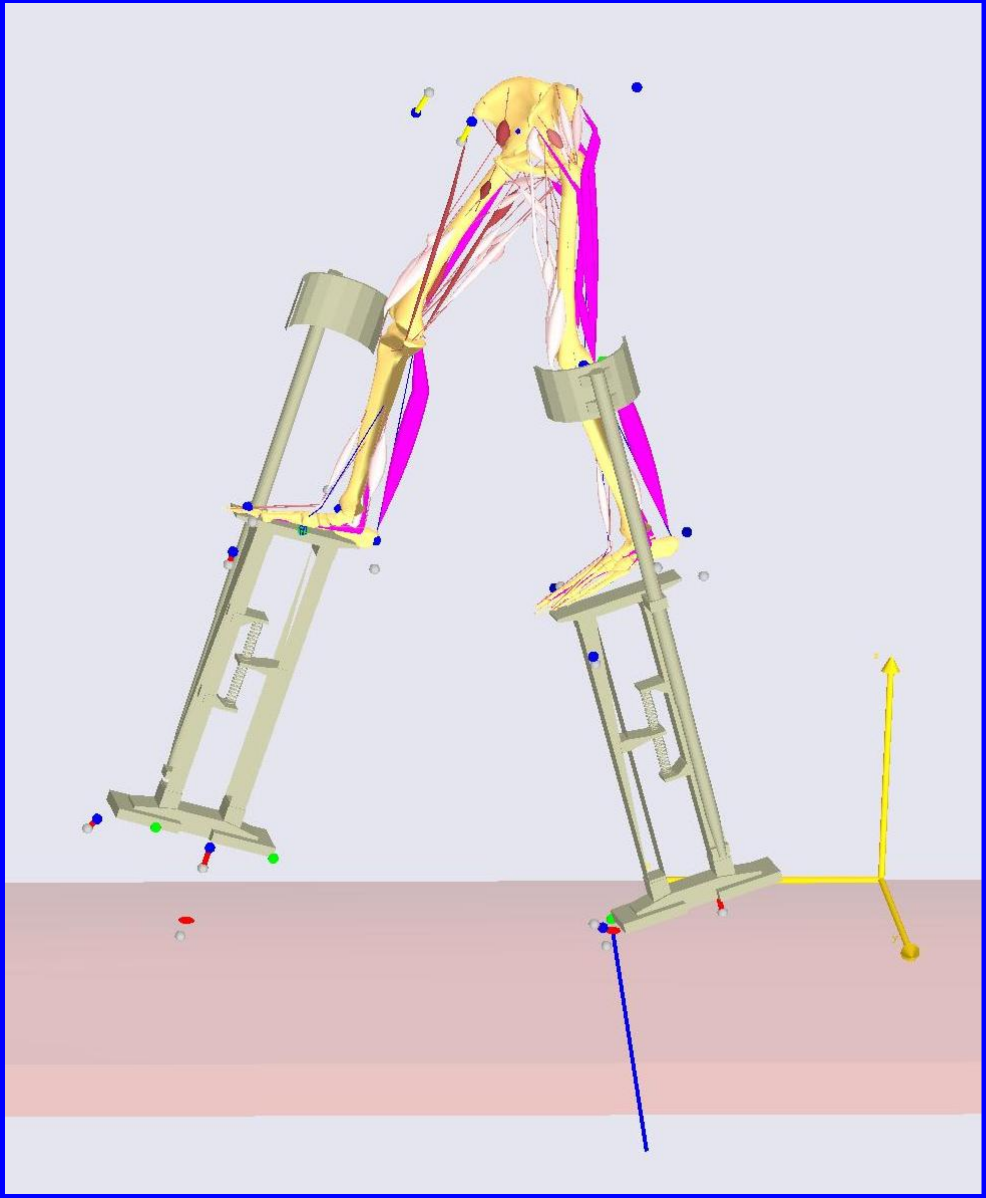
Method: human model





Method: stilts walking model





Muscle forces

- To make our results comparable with those in literature (Anderson, 2003; Thelen, 2006), we analyzed the muscle forces in eight muscle or muscle groups: SOL (soleus), GAS (gastrocnemius), GMAX (gluteus maximus), VAS (vastii, i.e., vastus lateralis, vastus medialis, and vastus intermedius), RF (rectus femoris), HAMS (hamstring muscle group, which includes semitendinosus, semimembranosus, biceps femoris caput longum, and biceps femoris caput breve), GMEDP (posterior gluteus minimus/medius), and GMEDA (anterior gluteus minimus/medius).

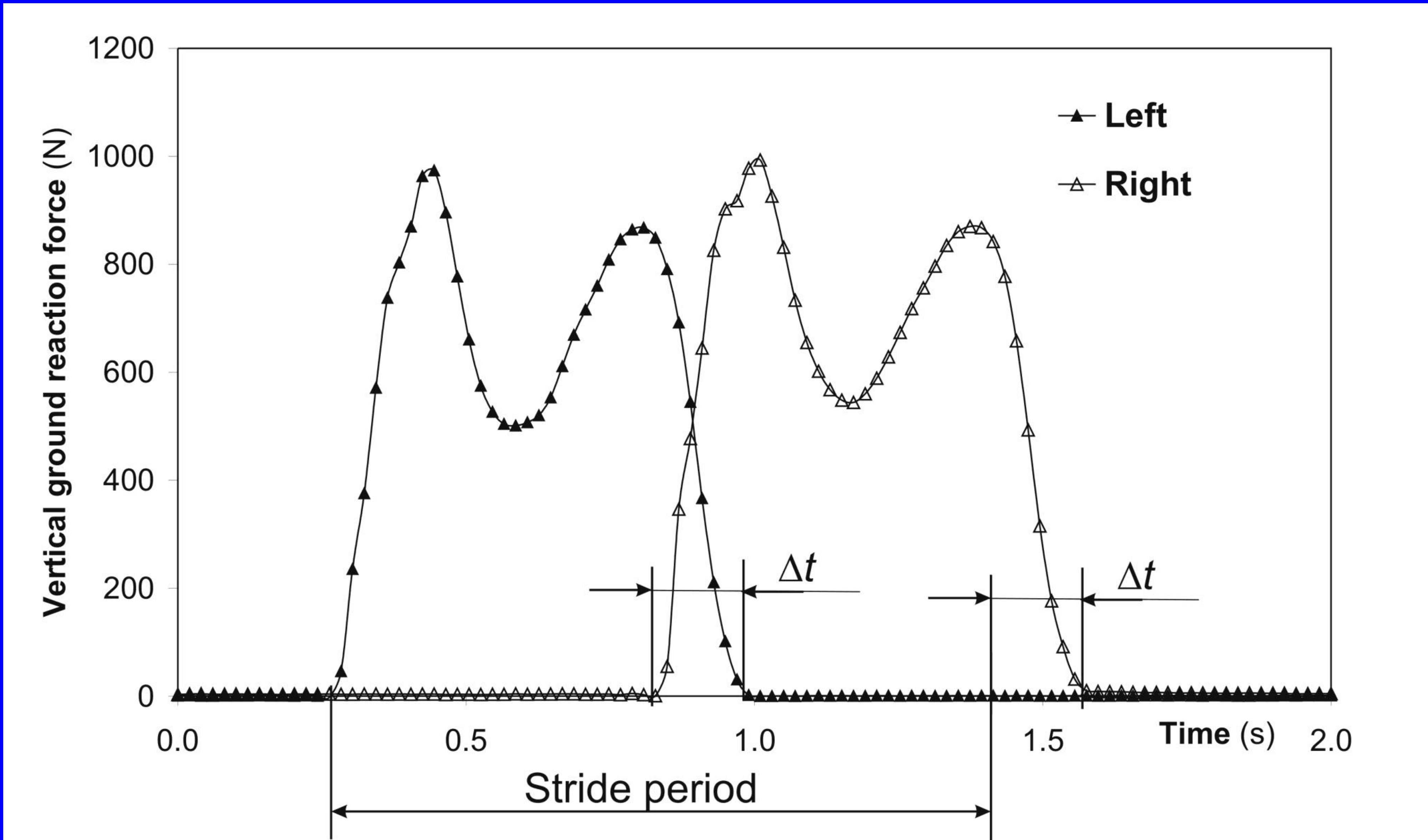
- The loading levels of the muscles or muscle groups were evaluated by normalized muscle forces. The normalized muscle forces were calculated by dividing the actual muscle force by the maximal isometric force, which was estimated by the physiological cross-sectional area (PCSA) multiplied by a muscle strength factor (35 N/cm^2).

Model structures and details …….

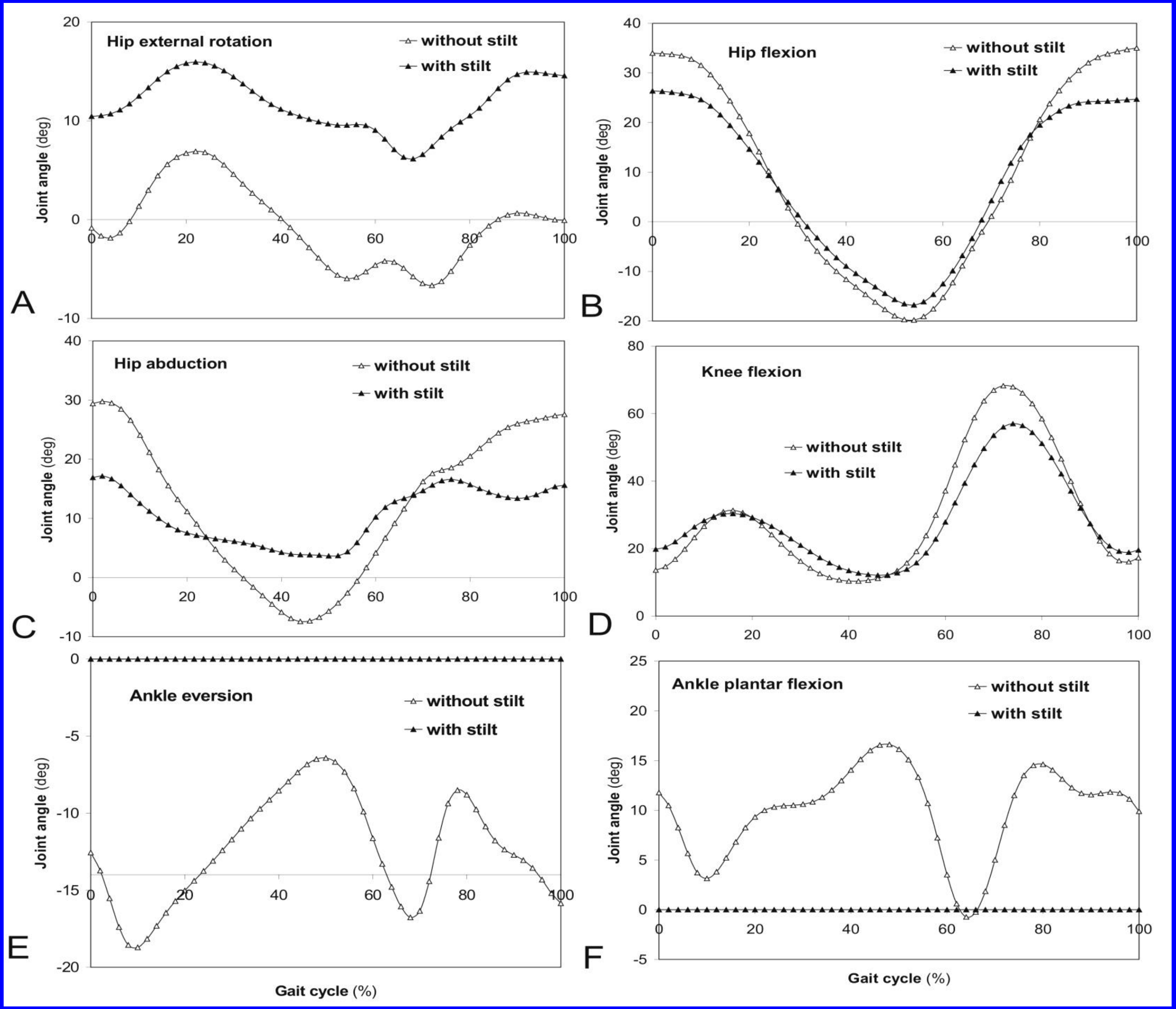
Analysis procedure

- The model was driven by the motion markers; and the ground reaction forces were applied as boundary conditions.
- The simulations were run twice:
  - first run – calculation of the joint moments. The simulations were performed by applying ``universal joint muscles" on each joint.
  - second run -- the three-element muscle models were applied and the time-histories of the muscle forces were calculated.

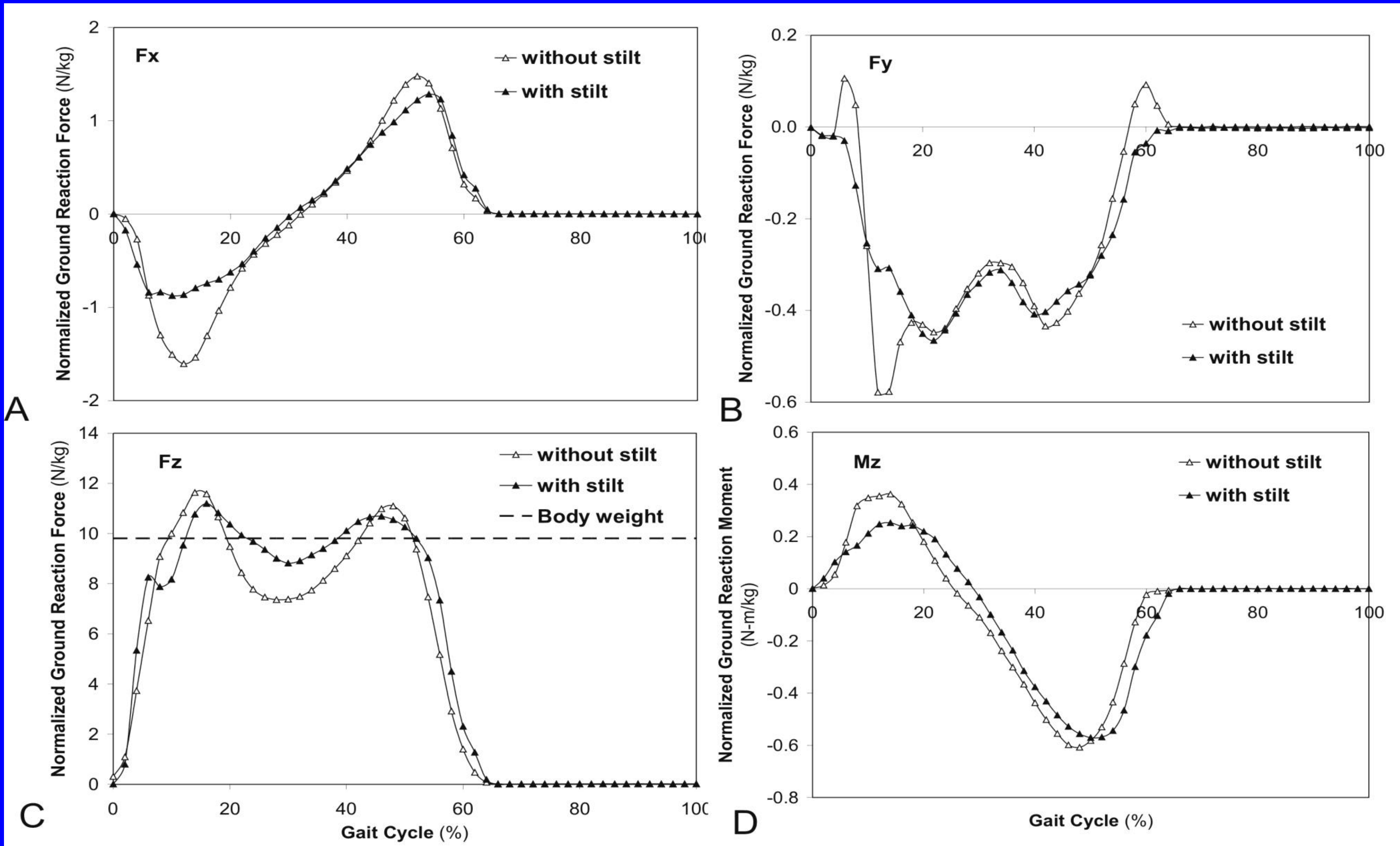
Stride Period



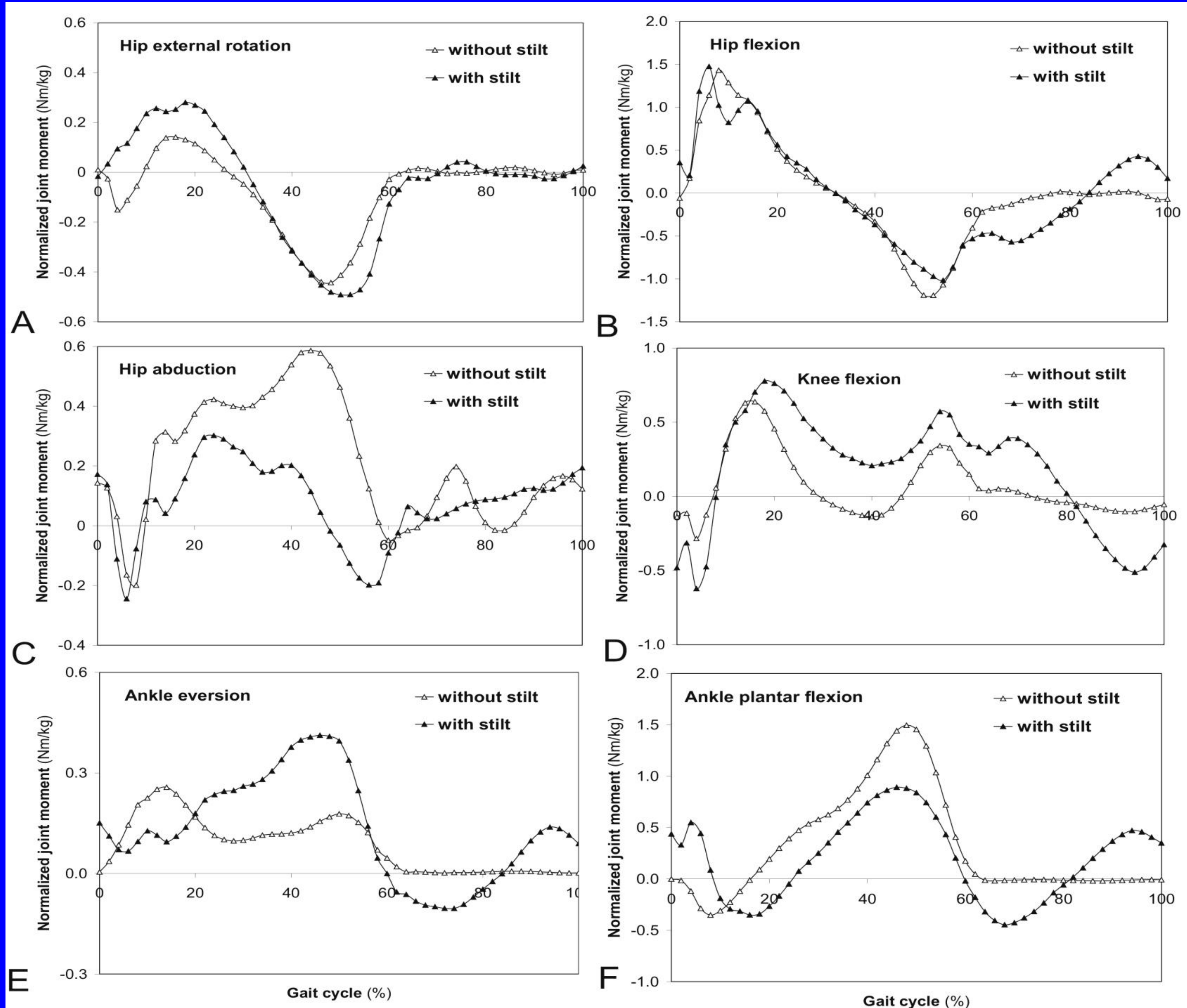
Joint angles



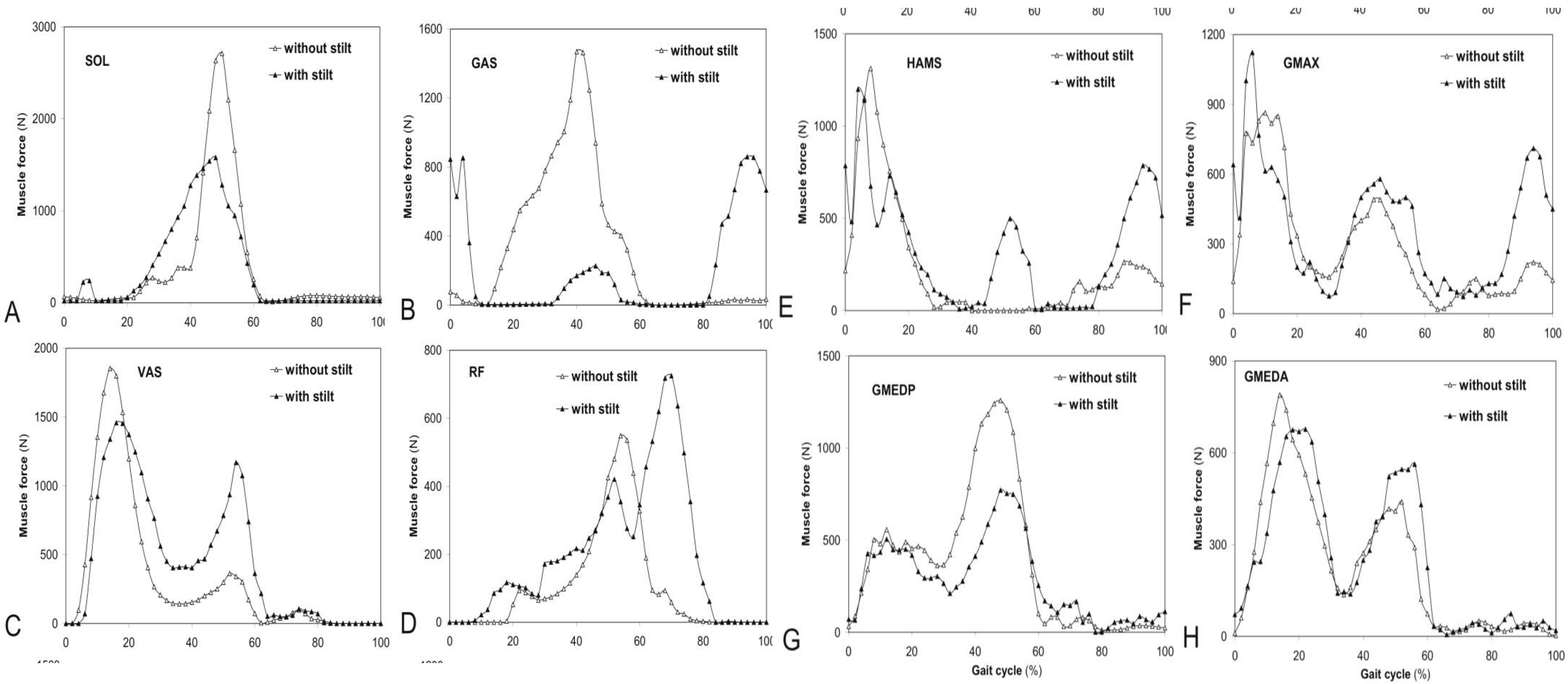
Typical ground reaction force



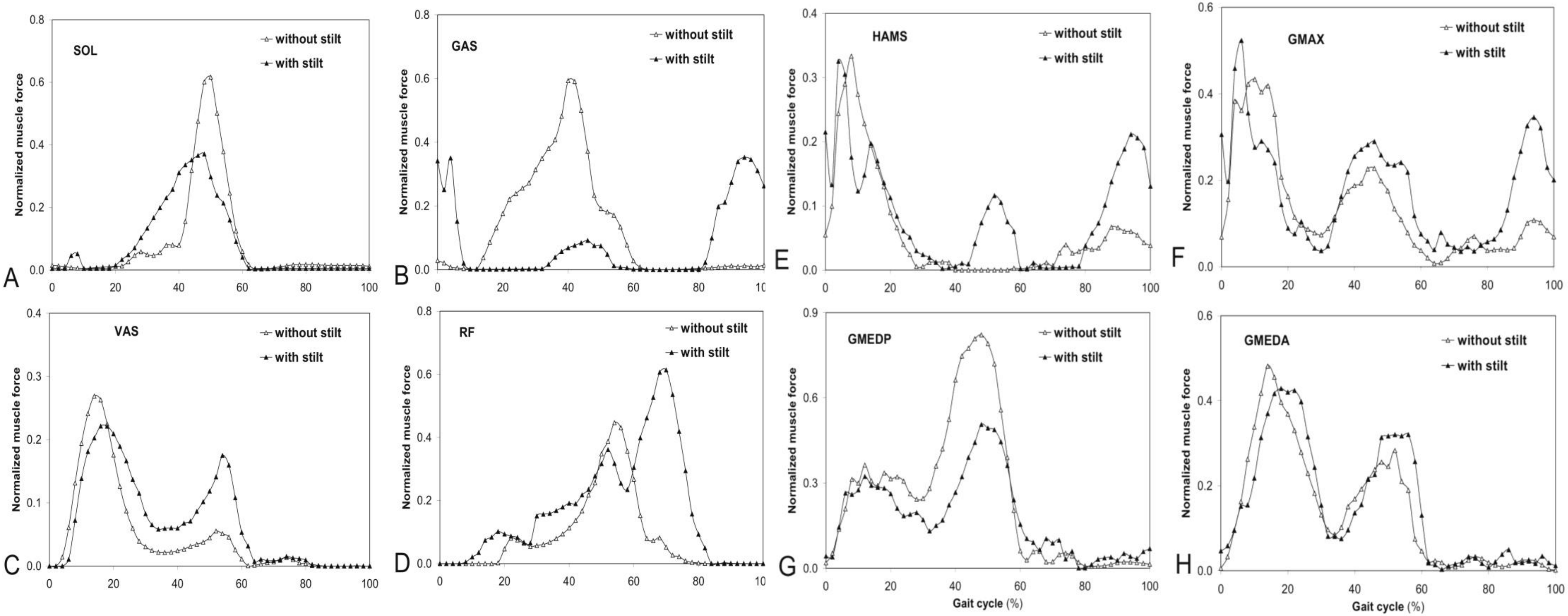
Joint moments



Muscle forces



Normalized muscle forces



Discussion

- The use of stilts may potentially cause an increase of peak joint moments in the knee extension by approximately 25%, while induced slight reductions in peak joint moments of hip and ankle.

- For the eight muscles groups analyzed, the forces in five muscle groups were increased, whereas those in three muscle groups were decreased due to the stilts use.

Summary

- The proposed model would provide a tool for the engineers in their efforts to improve the stilts design to reduce musculoskeletal loadings and fall risk.

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Analysis of Musculoskeletal Loadings in Lower Limbs During Stilts Walking in Occupational Activity

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Thank You !

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Q&A Session

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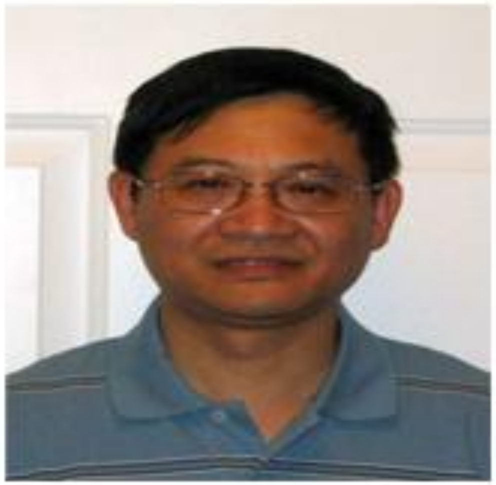

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