

# A muscle-reflex model that encodes principles of legged mechanics, produces human walking dynamics and muscle activities

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**Authors:** H. Geyer and H. Herr

Jhon Charaja<sup>1</sup> and Luca Borgonovi<sup>1</sup>

<sup>1</sup>Universidade de São Paulo, Brasil

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# Table of contents

## 1 Motivation

## 2 Objective

## 3 Methodology

- New model of human lower limb
- General equation of muscle stimuli
- Muscle stimuli during the stance phase
- Muscle stimuli during the swing phase

## 4 Results

# Motivation

The bipedal spring-mass model could describes the legged locomotion dynamics<sup>1</sup>

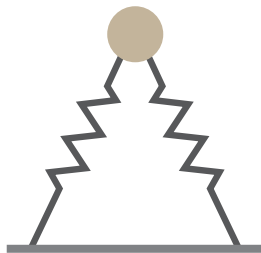


Figure: Spring-loaded inverted pendulum (SLIP)

- SLIP model describes the dynamics during walking and running<sup>1</sup>
- SLIP model is based on self-stability and compliant leg behavior principles<sup>2</sup>
- SLIP model does not present a clear relation with human motor control<sup>2</sup>
- Spinal reflexes can relate sensory information of leg with muscle activation<sup>2</sup>

<sup>1</sup>H. Geyer (2006).

<sup>2</sup>H. Geyer (2010).

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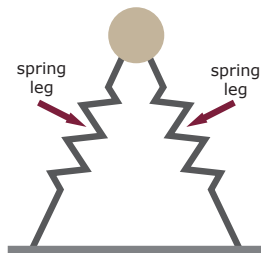


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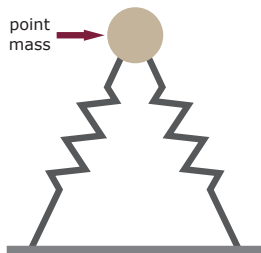


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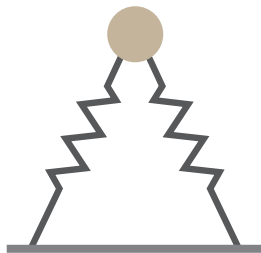


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# Table of contents

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**To develop a neuromuscular human model  
that encodes the principles of legged  
locomotion with muscular reflexes**



# Table of contents

1 Motivation

2 Objective

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4 Results

# Table of contents

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2 Objective

3 Methodology

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# New model of human lower limb

- Replacing the spring leg with a segmented leg

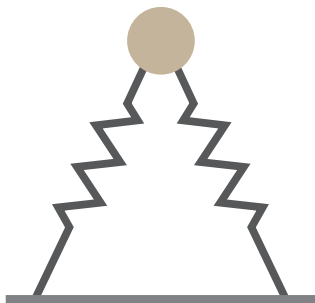


Figure: Spring-loaded inverted pendulum (SLIP)

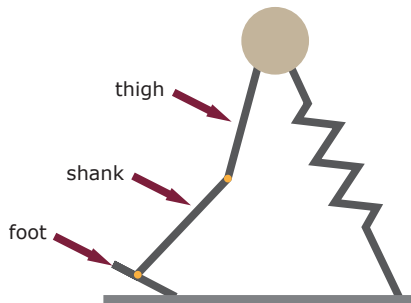


Figure: New model with three segment leg

# New model of human lower limb

- Replacing the point of mass with a trunk

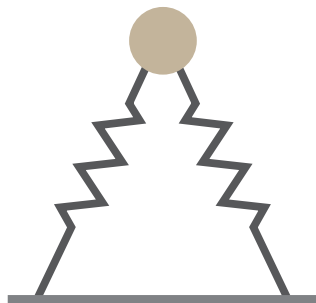


Figure: Spring-loaded inverted pendulum (SLIP)

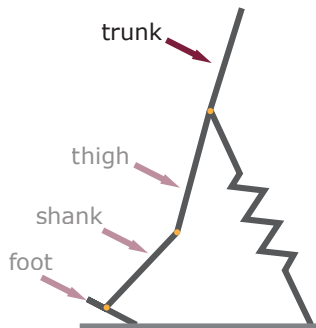


Figure: New model with three segment leg and a trunk

# New model of human lower limb

- Vastus group muscle (VAS) generates knee extension motion
- Soleus muscle (SOL) generates ankle plantarflexion motion

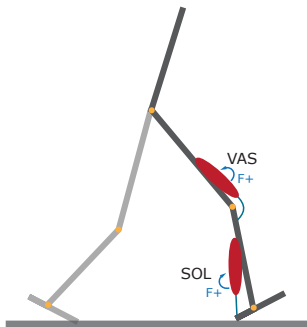
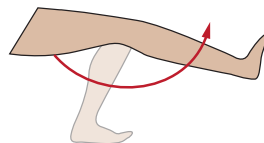


Figure: New bipedal locomotion model with muscles



(a) Knee extension



(b) Ankle dorsiflexion

# New model of human lower limb

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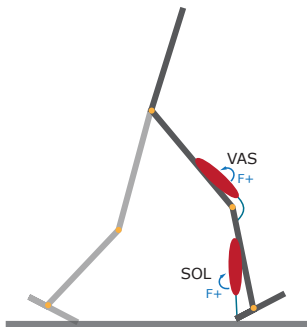


Figure: New bipedal locomotion model with muscles

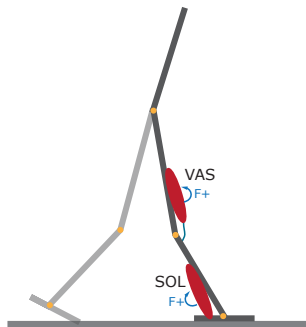


Figure: overextension case

# New model of human lower limb

- Gastrocnemius muscle (GAS) generates knee flexion and ankle plantarflexion motion
- Tibialis anterior muscle (TA) generates ankle dorsiflexion motion

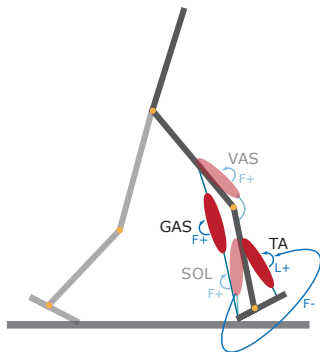


Figure: New bipedal locomotion model with muscles

- GAS prevents knee overextension
- GAS contributes to generate compliant behavior
- TA prevents ankle overextension

# New model of human lower limb

- Gluteus muscle group (GLU) generates negative orientation
- Hip flexor muscle group (HFL) generate positive orientation

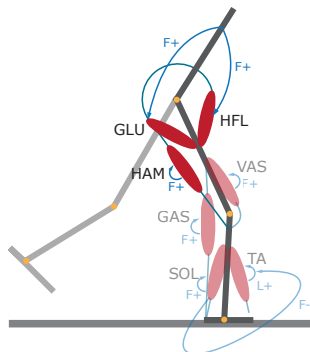


Figure: New bipedal locomotion model with muscles

- GLU and HFL maintain the balance of the trunk
- Hamstring muscle group (HAM) prevents knee hyperextension



# Table of contents

1 Motivation

2 Objective

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4 Results

# General equation of muscle stimuli

- Spinal reflexes activate muscles during locomotion

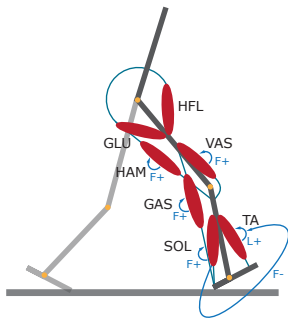


Figure: New bipedal locomotion model with muscles

The stimulation of a muscle is given by

$$S_m(t) = S_{0,m} + G_m F_m \delta t_m,$$
$$\delta t_m = (t - \Delta t_m),$$

where,

- $S_m$ : stimulation
- $S_0$ : prestimulation
- $F_m$ : force
- $G_m$ : gain
- $\Delta t_m$ : muscle time delay
- $\Delta L_m$ : muscle stretch

# Table of contents

1 Motivation

2 Objective

3 Methodology

- New model of human lower limb
- General equation of muscle stimuli
- **Muscle stimuli during the stance phase**
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4 Results

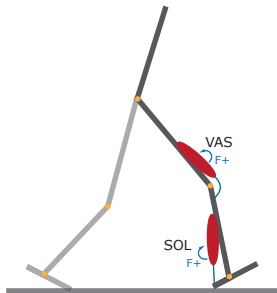
# Stance phase: initial contact

The stimulation of **VAS** is given by

$$S_{VAS}(t) = S_{0,VAS} + G_{VAS}F_{VAS}(t - \Delta t_{VAS})$$

The stimulation of **SOL** is given by

$$S_{SOL}(t) = S_{0,SOL} + G_{SOL}F_{SOL}(t - \Delta t_{SOL})$$



- Vastus group muscle (VAS) generates knee extension motion
- Soleus muscle (SOL) generates ankle plantarflexion motion

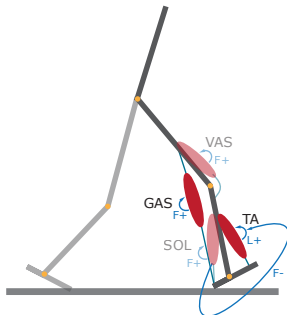
# Stance phase: initial contact

The stimulation of **GAS** is given by

$$S_{GAS}(t) = S_{0,GAS} + G_{GAS}F_{GAS}(t - \Delta t_{GAS})$$

The stimulation of **TA** is given by

$$S_{TA}(t) = S_{0,TA} + G_{TA}(\Delta L_{TA})(t - \Delta t_{TA}) - G_{SOL,TA}F_{SOL}(t - \Delta t_{SOL})$$



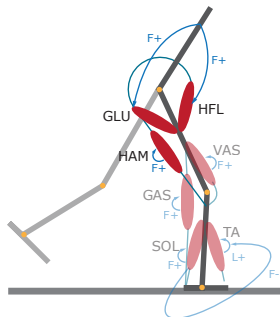
- GAS prevents knee overextension
- GAS contributes to generate compliant behavior
- TA prevents ankle overextension

# Stance phase: loading response

The stimulation of **GLU** and **HFL** is given by

$$S_{GLU}(t) \sim k_p(\theta - \theta_{ref})_{GLU} + k_d\dot{\theta}_{GLU},$$

$$S_{HFL}(t) \sim k_p(\theta - \theta_{ref})_{HFL} + k_d\dot{\theta}_{HFL}$$



The stimulation of **HAM** is given by

$$S_{HAM} \sim S_{GLU}$$

- GLU generates negative orientation
- HAM prevents knee hyperextension
- HFL generate positive orientation

Figure: New bipedal locomotion model with muscles

# Table of contents

1 Motivation

2 Objective

3 Methodology

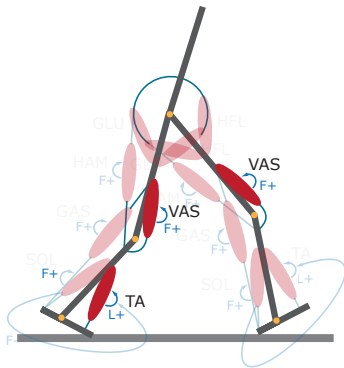
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4 Results

# Swing phase: pre-swing

The new stimulation of **VAS** is given by

$$S_{VAS}(t) = S_{0,VAS} + G_{VAS}F_{VAS}(t - \Delta t_{VAS}) - k_{bw}|F_{leg}^{ctr}|$$



where,

- $k_{bw}$ : gain proportional to body weight
- $F_{leg}^{ctr}$ : force applied on contralateral leg

The VAS of swing leg should be inhibited to allow compliance behavior

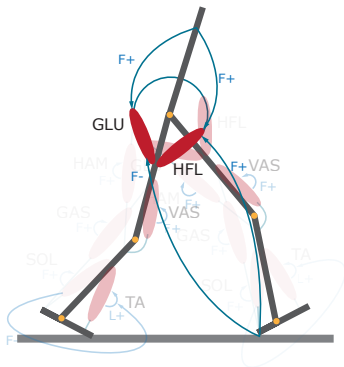


# Swing phase: pre-swing

The new stimulation of **HFL** and **GLU** is given by

$$S_{HFL}(t) = k_p(\theta - \theta_{ref})_{HFL} + k_d\dot{\theta}_{HFL} + \Delta S,$$

$$S_{GLU}(t) = k_p(\theta - \theta_{ref})_{GLU} + k_d\dot{\theta}_{GLU} - \Delta S$$



where,

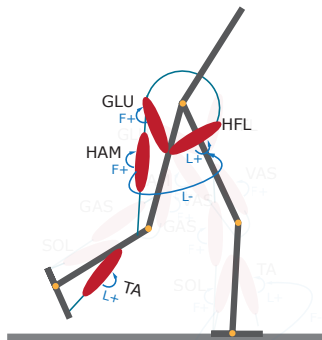
- $\Delta S$ : constant parameter

The model initiate swing increasing HFL and decreasing GLU stimulation

# Swing phase: initial swing

The new stimulation of **HFL**, **GLU** and **HAM** is given by

$$\begin{aligned}S_{HFL}(t) &= k_p(\theta - \theta_{ref})_{HFL} + G_{HFL}\Delta L_{HFL} - G_{HAM,HFL}\Delta L_{HAM}(t - \Delta t_{HAM}), \\S_{GLU}(t) &= S_{0,GLU} + G_{GLU}F_{GLU}(t - \Delta t_{GLU}), \\S_{HAM}(t) &= S_{0,HAM} + G_{HAM}F_{HAM}(t - \Delta t_{HAM})\end{aligned}$$



The new formulation improve gait stability by enforcing swing-leg retraction

# Table of contents

- 1 Motivation
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