FES-supported standing up by independent control of three global variables - a modelling study

5 authors, including:


Peter H Veltink
University of Twente


Theo J.A. De Vries
University of Twente

FES-supported standing up by independent control of three global variables - a modelling study

Peter H. Veltink[1], Olav Boiten[1], Ron Jacobs[1], Theo J.A. de Vries[1] and Gert Baardman[2]
[1]University of Twente and [2]Roessingh Research and Development,
Enschede, the Netherlands

***Abstract* - According to the work of Jacobs [1], we propose to control standing-up by applying independent controllers of three global variables (length *l* and orientation φ of the vector between ankle and body center of mass (CoM) and the orientation θ of the trunk). Furthermore, we propose to control *l* by modulating the activation of mono-articular muscles and to control φ and θ by modulating the activation of biarticular muscles (see also [1]). This division of tasks between mono- and biarticular muscles was found in postural control in cats [2].**
Our simulations indicate that effective and well co-ordinated standing up may be achieved using this concept, allowing for a range of initial postures and arm support forces.

I. Introduction

Standing up is an important task to be restored in paraplegic individuals, since it enables them to stand, handle objects which cannot be reached from the wheelchair and talk to other people face to face.

It is a challenge to design relatively simple control strategies for such complex tasks as standing up. An efficient and safe transfer from sit to stable stance requires the co-ordinated contractions of many muscles.

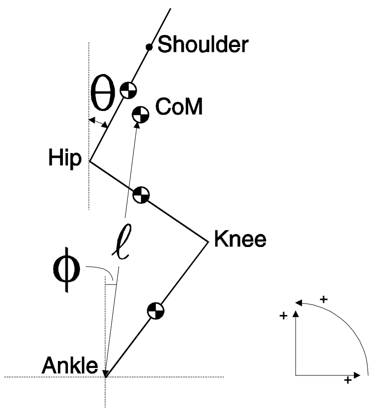

Figure 1. Definition of the global variables to be controlled independently during standing-up

The control concept described in this paper is based on the work of Jacobs [1], who proposed a control model of human stance, independently controlling the following three global variables (figure 1):

- length *l* of the vector connecting ankle and body center of mass (CoM).
- angle φ of this vector.
- trunk angle θ.

Jacobs [1] also proposed to differentiate between mono- and biarticular muscles in their task in postural control. This was based on the results of Jacobs and Macpherson [2], who investigated postural control during stance in cats. They concluded that activation of monoarticular muscles was mainly related to required anti-gravity support, while the activation of biarticular muscles were primarily related to the control of contact force direction.

On the basis of these findings Jacobs [1] proposed to control variable *l* by modulating the activation of the monoarticular extensor muscles, while the angles φ and θ are to be controlled by modulating the activation of biarticular muscles acting around the ankle and knee and around the knee and hip respectively.

The global control model of human stance described by Jacobs [1] may be a suitable approach for the control of FES supported mobility. For this reason, we investigated the control of FES supported standing up using this control strategy. This paper reports about a simulation study using a 2D 3 link model of the human body. First, the independent controllers for the global variables were tested separately in simplified link models. Subsequently, the controllers were applied simultaneously.

II. Methods

- SISO PD controllers were used to control each of the three global variables. The controllers for *l*, φ and θ were tuned in simulations on an inverted pendulum. The control objective was to change both *l* and φ from an initial value (sit) to a reference value (stance) (step response).
- Subsequently all three controllers were applied on the 3-link 2D model of the human body (figure 1). Minimal retuning of the controllers was performed if necessary.
- The control of standing up was simulated starting from a range of initial postures.
- Upper body support was simulated by an extra force acting at the shoulders. The influence of the direction and size of the force on successful standing-up was investigated.

III. Results

Figure 2 shows the joint angles and activation of mono- and biarticular muscles during standing up with the three link model. After tuning of the separate controllers in the single inverted pendulum simulations, only the D gain of the *l* controller had to be adjusted. The output limitations of the mono-articular muscles were limited to 200 Nm.

Without the addition of arm support and without adjusting controller setttings successful standing-up was achieved for a range of initial values φ of 10 degrees around vertical.

Subsequently, an exponentially decaying force was added at the shoulder, representing upper body effort. This force had an initial magnitude of 300 N and a time constant of 5 s, and varying directions of application γ. The maximal torque of the monoarticular muscles was reduced to 80 Nm (total of both legs), modelling the situation in most paraplegics where additional arm support is required for FES-supported standing-up. Successful standing-up was achieved at directions γ between 18 and 72 degrees.

IV. Discussion

The simulation results indicate that the proposed strategy for control of standing-up by independent control of three global variables is a promising approach.

In actual use of this control strategy in paraplegic subjects it should be noted that the voluntary control of upper body effort is independent of the artificial control of the paralyzed muscles in the legs. We propose that the moments of force generated by the upper body effort around ankle, knee and hip joints are constantly estimated (like [3]) and subsequently subtracted from the required joint moments continuously, thus giving the joint moments to be generated by the stimulated muscles ([4], unlike [3]). In addition, the subjects can adaptively learn to minimize their upper body efforts to a safe minimum. For this they may require additional sensory feedback.

V. Acknowledgements

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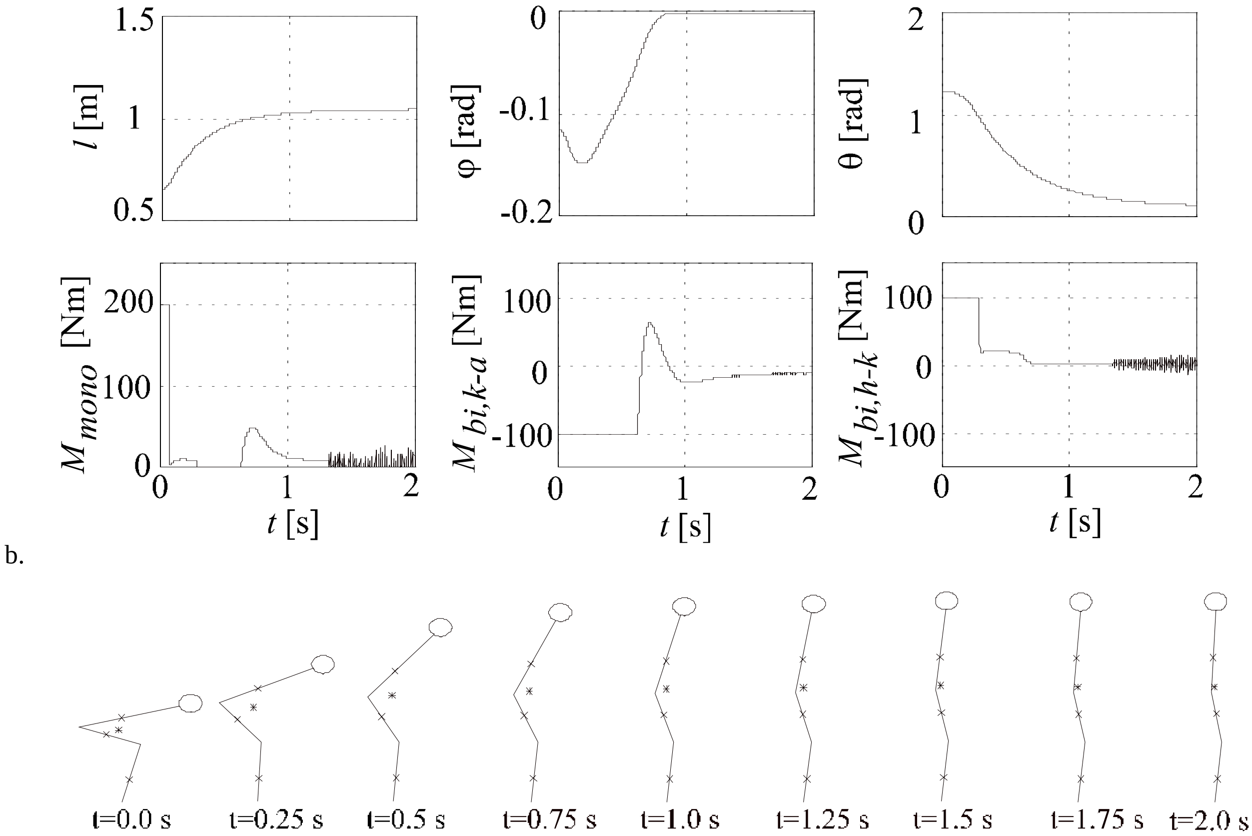
a.



<u>Figure 2.</u> simulation of standing up using independent control of global variables:
a: the global variables l, φ and θ and joint moments produced by mono- and biarticular muscles
M_{mono} is the moment produced by monoarticular muscles around hip, knee and ankle;
$M_{bi,k-a}$ and $M_{bi,h-k}$ are moments produced by biarticular muscles around knee and ankle, repectively hip and knee.
b: stick figures illustrating simulated standing up