PARADOXICAL MUSCLE MOVEMENTS IN HUMAN STANDING

[1] Ian Loram, [2]Constantinos Maganaris and [1]Martin Lakie
[1]The University of Birmingham, UK, email: i.d.loram@bham.ac.uk
[2]Manchester Metropolitan University, UK; email: c.n.maganaris@mmu.ac.uk

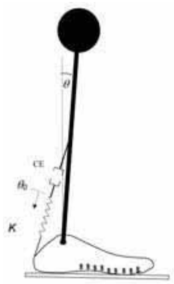

Figure 1: Dynamic bias model**.** CE, contractile element. K, s.e.c., θ COM angle, θ_0 bias exerted on s.e.c. spring.

INTRODUCTION

In human standing the calf muscles soleus and gastrocnemius actively prevent forward toppling about the ankles. It has been generally assumed that these postural muscles behave like springs with dynamic stiffness reflecting their mechanical properties, reflex gain including higher derivatives, and central control. We have used an ultrasound scanner and automated image analysis to record the tiny muscular movements occurring in normal standing and during large voluntary sways. This new, non-invasive technique resolves changes in muscle length as small as 10 microns without disturbing the standing process. This technical achievement has allowed us to test the long established mechano-reflex, muscle-spring hypothesis that contractile element length changes in a spring-like way during sway of the body.

METHODS

Ten subjects stood freely on a footplate that measured ankle torque. Ankle angle was recorded using a laser range finder reflected off the shin. Surface EMG were recorded from left soleus and gastrocnemius. An ultrasound scanner (Esaote Biomedica AU5) recorded 40 s (1000 frames) of sonographs focused on the distal aponeurosis of left soleus and gastrocnemius. Image markers were placed on the proximal and distal aponeurosis of the two muscles. Spatial cross correlation was used to track the changes in position of these markers throughout the 1200 frames. From the differential movement of these markers continuous changes in the length of the contractile element were calculated [1, 2].

Cross correlation was used to assess the relationship between changes in muscle length and changes in CoM angle. A simple model was constructed (Figure 1), incorporating a spring for the s.e.c. of the calf muscles, a contractile element for the muscles and a single mass for the body during standing sagital sway. Using the model and measured values of ankle torque and CoM angle, we computed the predicted cross correlation between muscle length and CoM angle for a variety of values of s.e.c. stiffness. By comparing the actual cross correlation with the predicted, we estimated the stiffness of the s.e.c.

RESULTS AND DISCUSSION

The contractile elements are longest when the subject is closest to the vertical and shorten as the subject sways forwards (paradoxical movements). In quiet standing, muscle length fluctuates at approximately three times the frequency of body sway: on average, shortening during forward sway and lengthening during backwards sway (Figure 2). This counter-intuitive result is consistent with the fact that calf muscles generate tension through a series elastic component (s.e.c., Achilles tendon and foot, Figure 1) which limits maximal ankle stiffness to 92% ± 20% (± S.D) of that required to balance the body (Figure2). The higher frequency of muscle fluctuation is consistent with a central, impulsive controller [3].

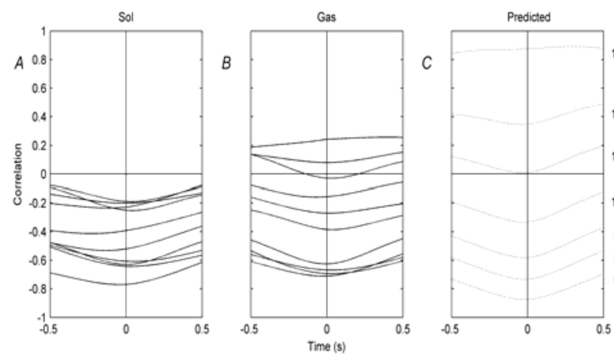

Figure 2 Cross correlation between **A** soleus, **B** gastrocnemius muscle length and centre of mass angle. Each line represents the mean of 6 trials for one subject. **C** shows the predicted correlation for a variety of values of s.e.c. stiffness expressed relative to the load stiffness.. The time lag is shown horizontally.

CONCLUSIONS

The intrinsic length-tension relationship of the calf muscles partially stabilizes the human body in quiet standing while leaving the body mechanically unstable. Stability and balance is achieved by a higher level impulsive process that is poorly correlated with CoM angle.

REFERENCES

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3. Loram ID, et al. *J Physiol*, **in press**, 2005b.