Numerical simulation and justification of antagonists in isometric squatting

M. Damsgaard, J Rasmussen, and S. T. Christensen

Institute of Mechanical Engineering, Aalborg University, Aalborg, Denmark

Introduction

Lombard's paradox [1][2], the observation that bi-articular muscles can be observed active in opposition to one of their joint moments, is one of several phenomena related to the control of human muscles that are difficult to understand from an intuitive point-of-view. Another example is mono-articular antagonists.

When interpreting the effects of particular muscle actions is important to bear in mind, that the musculo-skeletal system is a *system* of interconnected elements and must be studied as such. In-vivo experiments to obtain detailed information about the control of individual muscles are technically and/or ethically difficult to conduct, and the basis of the present work is consequently the idea that much insight can be obtained from the study of numerical models, provided they can be shown to reproduce the experimentally observed phenomena. This paper describes some simple simulations that are the basis for the development of a general body modeling software system by the name of AnyBody. We show that a simple mechanical model of the human leg can reproduce Lombard's paradox, predict mono-articular antagonists, and provide rational explanations for both phenomena.

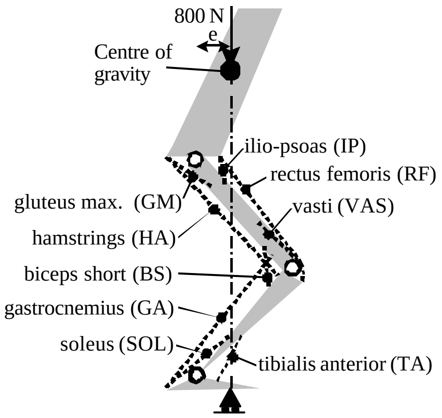

Fig. 1:Model of leg with nine muscles.

Methods

A mechanical model of the body or a particular limb is developed. As an example, we shall here use the simple model of the human leg depicted in Fig. 1. Isometric conditions are assumed, and we use approximate antropometric data from the sources at hand, as our aim is merely to show qualitative behavior. The muscle load distribution is solved by a min/max criterion, minimizing the maximum muscle activity defined as the muscle force, F, divided by the strength, N. Details on this approach are explained in [3]. We can vary the loading by the eccentricity parameter, e (Fig. 1), that is, the joint moments produced by the muscles depend on e, and we shall study the muscle recruitment for different values of e.

Results

In Fig. 2 the muscle activities, F/N, are shown for the active muscles. The curves are dominated over the entire interval by the quadriceps. For values of e larger than 32 mm it is evident that the hamstrings are also active, in accordance with Lombard's paradox. Another interesting observation is that GM exhibits activity for negative values of e, i.e., antagonistically to the hip moment.

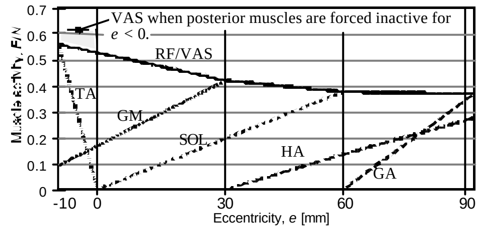

Fig. 2:Muscle activities for varying eccentricity, e.

Discussion and conclusions

The min/max criterion strives to minimize the maximum activity of any muscle for each value of e. This explains Lombard's paradox: as e increases, GM increases its activity to balance the hip moment, until it reaches the activity level of the quadriceps. At this point, GM would become the maximally activated muscle, unless another muscle could contribute to balancing the hip moment. HA can do that, but they also flex the knee and thereby cause additional activity in the quadriceps, causing them to drop off less rapidly.

Similar observations explain the antagonist activity of gluteus maximus for negative e. The balancing of the knee causes maximum activity of VAS, and is therefore desirable to have RF contribute to this task. This creates an imbalance in the hip even for negative e values that must be counteracted by GM. Experimentally, we may disallow activity of posterior muscles when e is negative. The hatched area in Fig. 2 shows the additional activity of VAS that such a constraint creates, and we see that the seemingly antagonist activity of GM helps reducing the maximal load on the muscles.

The choice or even existence of a criterion for recruitment of redundant muscles is still an unresolved matter. In this work we have used the min/max criterion because we believe that it can be physiologically justified, and because it is a "clean-cut" criterion that makes interpretation very easy. However, the reproduction of Lombard's paradox and the antagonist gluteus maximus could also be obtained by, say, polynomial recruitment criteria, provided they are of sufficiently high order as explained in [3].

The generality and efficiency of the numerical approach allows for similar studies of more complex cases. Implementation into software for general body modeling is in progress.

References

[1] W. P. Lombard (1903) The action of two-joint muscles. Am. Phys. Ed. Rev., 8, 141-145. [2] R.J. Gregor, P.R. Cavanagh, M. LaFortune (1985) Knee flexor moments during propulsion in cycling – a creative solution to Lombard's paradox, J. Biomechanics, 18, 307-316. [3] J. Rasmussen, M. Damsgaard, M. Voigt (2000) Muscle recruitment by the min/max criterion, part 1: background and theory. Submitted for publication.

Acknowledgements
This work was supported by the Danish Research Agency, program on simulation and optimization of musculo-skeletal systems.