Solving the muscle redundancy problem with EMG input: application to back muscles for the Sorensen test posture

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EXTENDED ABSTRACT

1 Introduction

When solving inverse dynamics in the human body with a pure mathematical approach such as optimisation, the problem of muscle redundancy occurs, i.e. there is an infinity of solutions of muscle forces for a given configuration. To solve this problem, many efforts have been done to define cost functions for the optimisation process which give the most physiological muscle forces. These cost functions may require parameters that are difficult to estimate and need an experimental validation afterwards.

Another approach is to use relevant information from an upfront experiment prior to the quantification of muscle forces with a multibody (MBS) model. One way to collect experimental measurements is electromyography (EMG), i.e. recording muscle activity. EMG can be used as input at two levels: (i) to include in the MBS model only the muscles which were actually active during the experiment and (ii) to define a muscle force distribution or to guide the optimisation process towards a more realistic and physiological solution.

In this work, an EMG-based approach previously presented [1] is used to predict muscle forces and intervertebral efforts in the lumbar spine for a static configuration in the Sorensen test posture. Muscles forces and intervertebral efforts are compared with these from a purely mathematical approach. The novelty in this work is to compare different muscle strategies asked to the participant during the experiment. While the purely mathematical computation cannot see any difference, it is believed that the solutions based on EMG reflect reality better.

2 Materials and Methods

One male subject (28-year old, 175-cm height, 90-kg mass) was asked to produce three different muscle strategies in the Sorensen test posture. Lying on a table in the prone position with the trunk unsupported, the subject had to maintain the trunk aligned with the lower limbs while (i) being the most relaxed as possible (relaxed configuration), (ii) being the most stressed as possible (stressed configuration) and (iii) being in an intermediate level between the most relaxed and the most stressed configurations (mid configuration). EMG signals of lumbar (LP) and thoracic paravertebral (TP) muscles, quadratus lumborum (QL), latissimus dorsi (LD), rectus abdominis and externus obliquus were recorded during the experiment. Each configuration was performed without and with an external mass equal to 20% of the bodymass. Maximum voluntary contractions (MVC) of back and abdominal muscles were recorded prior to the exercises for EMG normalisation.

The MBS model of the trunk in the Sorensen posture (see Fig. 1 top left) was developed with the multibody software Robotran [2] and derived from a fully articulated thoracolumbar spine and rib cage model developed by Bruno et al. [3]. Based on EMG signals from the experiment, only back muscles, i.e. LP, TP and QL, were considered in the model.

Muscle forces for the EMG-based approach were quantified based on a deterministic muscle force distribution presented previously [1]. On the other hand, muscle forces for the optimisation computation were computed with a trust-region algorithm for constrained optimisation. Two cost functions among those proposed in the literature were used: minimising the sum of cubed muscles stresses (see Eq. 1) and minimising the largest relative muscle force (see Eq. 2).

$$\min \sum_i \left(\frac{F_i}{PCSA_i} \right)^3 \tag{1}$$

$$\min \max \left(\frac{F_i}{F_{max,i}} \right) \tag{2}$$

with F_i the force in the ith muscle fascicle, $PCSA_i$ its physiological cross-sectional area and $F_{max,i}$ its maximum isometric force.

For both EMG and optimisation computations, intervertebral efforts were computed at each lumbar disc level for comparison.

3 Results and Discussion

As expected, varied muscle strategies were obtained for the different configurations on the basis of recorded EMG amplitudes (see Fig.1 bottom left). For the relaxed and mid configurations and for the two loading condition, TP were the most recruited.

Both relaxed and mid configurations showed similar muscle patterns: LP and TP being the most recruited muscles followed by QL and LD. LP had the highest EMG amplitude in the stressed configuration with no load.

LD was not expected to be as active, specially with high EMG amplitudes for the three loaded configurations. This action may come from the bilateral role of LD in helping for hyperextension of the trunk [4]. Besides, for the stressed and loaded configuration, LD showed the highest EMG amplitude among all EMG amplitudes.

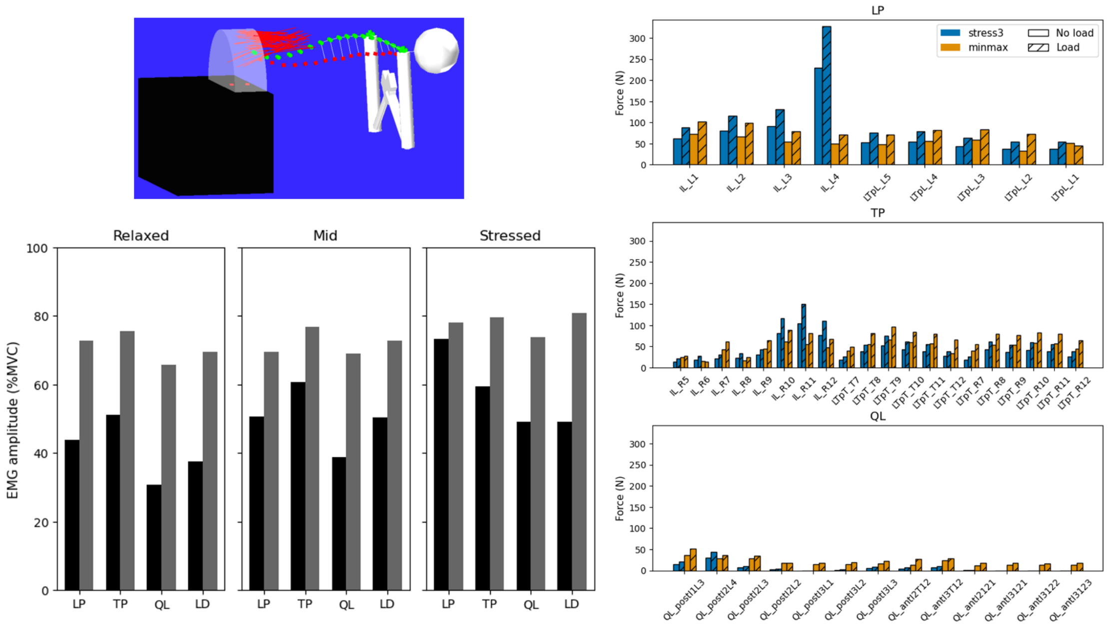

Figure 1: Top left: MBS model with LP, TP and QL muscle fascicles in red. Bottom left: EMG amplitudes (%MVC) for LP, TP, QL and LD in the three configurations (relaxed, mid and stressed) without (black bars) and with the 20%-bodymass external load (gray bars). Right: Forces in LP, TP and QL fascicles computed by optimisation for the two cost functions (blue for Eq. 1 and orange for Eq. 2) and for the two loading conditions (non-hatched and hatched bars).

For the optimisation computations, the three configurations could not be differentiated. The common solution to the three configurations is showed in Fig. 1 on the right for the two cost functions and the two loading cases. It means that one set of solutions, for example non-hatched blue bars standing for the non-loaded case solved by Eq. 1, is common to the three configurations actually performed during the experiment for the non-loading case. Furthermore, the two cost functions showed radically different solutions with a most distributed recruitment for Eq. 2 while minimizing the cubed muscle stresses favoured LP and TP muscles which had greater PCSA. Adding load shifted all forces higher.

4 Conclusion

EMG seemed to be a valuable input to study different muscle strategies for a same subject that could not be differentiated by optimisation computations. More results and discussion will be given at the oral presentation, namely with an in-depth comparison of the resulting intervertebral efforts and a sensitivity analysis with respect to LD activity to be included in the MBS model.

References

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