Open vs closed articular architecture of the forearm for an analysis of muscle recruitment during throwing motions

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Summary

The osteoarticular architecture of the forearm can be modeled by an open or a closed-loop. This study aims to compare the impact of the chosen architecture on the muscle activity for overhead throwing motions. Preliminary results show similar muscle behaviors with both models.

Introduction

Musculoskeletal modeling can analyze human motion from kinematics to muscle activity. The impact of modeling on the kinematic reconstruction of the motion has been studied [1]. This pilot study aims at comparing activations estimated with a full-body musculoskeletal model presenting an open-loop (OLM) [2] or a closed-loop (CLM) [3] model at the forearm during overhead throwing motions.

Methods

The OLM is based on [4] for the lower limb and [2] for the upper limb. Muscle activations are estimated by the following static optimization under the respect of dynamic equations [5]:

$$\min_{a} \sum_{i=1}^{m} a_i^2$$

$$\text{s. t.} \quad \begin{cases} 0 \leq a_i \leq 1, \forall i \in [\![1, m]\!] \\ H(q)\ddot{q} + C(q,\dot{q}) = R(q)F_{max} \odot a \end{cases}$$

The muscle force model is $F_m = F_{\max} a$, with a the muscle activations. q are the degrees of freedom, $H(q)$ is the mass matrix, $C(q,\dot{q})$ is the Coriolis matrix and the effect of external forces, $R(q)$ is the moment arm matrix from [6].

The CLM is based on [4] for the lower limb and [3] for the upper limb. The forearm contains a closed loop modeled by constraints $h(q) = 0$, contributing to dynamic equations via its Jacobian K and Lagrange multipliers λ [7]. The muscle recruitment problem is now:

$$\min_{a,\lambda} \sum_{i=1}^{m} a_i^2$$

$$\text{s. t.} \quad \begin{cases} 0 \leq a_i \leq 1, \forall i \in [\![1, m]\!] \\ H(q)\ddot{q} + C(q,\dot{q}) = R(q)F_{max}(q) \odot a \; + \; K^T\lambda \end{cases}$$

The study was implemented in CusToM [9], an open-source Matlab toolbox for musculoskeletal modeling. Geometrical and inertial parameters were extracted from [10] and scaled to the subject (1m74, 64kg) using the CusToM scaling routine. The raw data for 18 throwing trials were taken from [11].

Measured EMGs and activations computed from OLM and CLM were compared with phase error metrics [8].

Results and Discussion

OLM and CLM had similar results while compared to EMG measurements (Figure 1). This was confirmed by the OLM and CLM comparison, with phase errors under 25%.

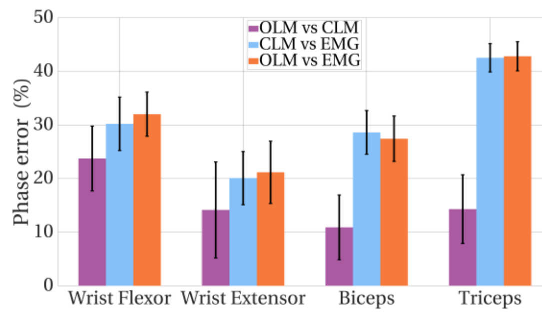

Figure 1: Phase error (%) of muscle activations

OLM and CLM were expected to have similar behaviors. However, adding constraints in the dynamic equations may impact the muscle recruitment to give a better match with measurements. We can see that constraints did not have a strong impact on these specific motions and that none of OLM or CLM fairly match EMG data. This could be explained by the small number of solids in the CLM and the relatively low level of solicitation related to this motion.

Conclusion

Finally, it seems that CLM did not bring any improvement compared to OLM for studying throwing motion. A similar study should be done for a larger cohort to validate these preliminary results. The same comparison could be done for shoulder models, using more complex constraints.

References

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