Studying the impact of internal and external forces minimization in a motion-based external forces and moments prediction method: application to fencing lunges

Pauline Morin, Antoine Muller, Charles Pontonnier, Georges Dumont

Studying the impact of internal and external forces minimization in a motion-based external forces and moments prediction method: application to fencing lunges

Pauline Morin[1], Antoine Muller[2], Charles Pontonnier[1], Georges Dumont[1]
[1]Univ Rennes, CNRS, Inria, IRISA - UMR 6074, F-35000 Rennes, France
[2]Univ Lyon, Univ Gustave Eiffel, Université Claude Bernard Lyon 1, LBMC UMR_T 9406, F-69675 Lyon, France
Email: pauline.morin@ens-rennes.fr

Summary

External forces and joint torques have been jointly minimized in a motion-based external force prediction method. The prediction of external forces during a fencing lunge demonstrates the interest to consider joint torques during static phases of movements.

Introduction

In motion analysis studies, classical inverse dynamic methods require ground reaction forces and moment (GRF&M) to compute internal forces. Predicting GRF&M from motion capture makes it possible not to measure them. In such a prediction method, contact is handled through multiple points, making the inverse dynamics problem undetermined. Physiological assumptions (like minimizing external forces) in an optimization approach enable to determine the most plausible solution from the mathematical variety of force distribution solutions [1]. This abstract presents a pilot study questioning the implication of the internal forces (considering joint torques) in external forces prediction during a fencing lunge.

Methods

The present study is a pilot study considering 10 lunges executed by one fencer (1.86m, 78.6 kg) issued from [2]. Lunge motion consists in an explosive extension of the front leg accompanying an extension of the sword arm. It admits a static (preparing the attack) and a dynamic phase (the lunge itself). Motion capture markers (46 on standardized anatomical landmarks) were recorded with an optoelectronic motion capture system Qualisys (200Hz). The external forces were recorded with two AMTI force platforms (2000Hz). The GRF&M were predicted from an optimization approach considering a set of discrete contact points. The cost function was a combination of a quadratic sum of external forces $||F||^2$ and a quadratic sum of joint torques $||\tau||^2$ as follow:

$$\min_{F}\left(w_{ext}\frac{||\mathbf{F}||^2}{F^{norm\,2}} + w_{int}\frac{||\boldsymbol{\tau}(\mathbf{F})||^2}{\tau^{norm\,2}}\right)$$

At each frame, the quadratic sum of external forces was normalized by the square of the norm of the global external force $F^{norm\,2}$ (computed from the inverse dynamic equilibrium). The quadratic sum of joint torques was normalized by the quadratic sum of joint torques considering equal to zero the external forces. The two terms were balanced by:

$$(w_{ext}, w_{int}) \in [0,1] \; s.t. \, w_{ext} + w_{int} = 1$$

This method has been implemented in the CusToM Matlab toolbox [3].

The external forces were predicted for different values of $(\boldsymbol{w_{ext}}, \boldsymbol{w_{int}})$: (1, 0), (0.75, 0.25), (0.5, 0.5), (0.25, 0.75) and (0,1). The efficiency of those predictions was evaluated comparing predicted GRF&M and force platforms data varying, in terms of RMSE. The results are presented for the static and the dynamic phases, detected visually on each trial.

Results and Discussion

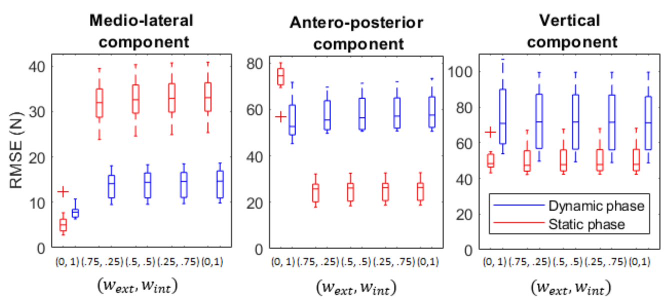

Figure 1: RMSE of the external force prediction for different (w_{ext}, w_{int}) values with a dynamic and static phase distinction.

The RMSE statistical repartition is presented in the Figure 1 for each resultant component. All non-zero values of w_{int} led to similar predictions in shape and amplitude. Considering joint torques in the prediction improved the antero-posterior component prediction and deteriorated the medio-lateral component prediction during the static phases. Considering joint torques in the cost function did not impact prediction during the dynamic phases. The studied motion admitted two easily identifiable phases (static and dynamic), and we may assume that joint torques were minimized during the static phase to let the fencer being relaxed before the assault. Any other motion may present specificities to be considered to find the best combination between internal and external forces to be minimized in the prediction.

In conclusion, minimizing joint torques and external forces in a motion-based external forces prediction method seems relevant for static phases of motions. A larger cohort should be considered to validate these preliminary results. Other motions presenting specific dynamical characteristics should also be considered.

References

[1] R. Fluit, et al. (2014) J. Biomech 47(10):2321–2329.
[2] Sorel A, et al. (2019). PLoS ONE
[3] A. Muller, et al. (2019). J. Open Source Softwa. 4(33):92