Towards the Use of Neuromusculoskeletal Modeling in Clinical Practice: A Feasibility Study in Parkinson Disease Patients

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Abstract Electromyography (EMG)-driven neuromusculo-skeletal models (NMSM) are currently used to estimate joint moments and muscle forces during dynamic movements considering subject-specific neural-excitation patterns provided by the EMG data. However, these models are rarely adopted in routine clinical applications. This is partly due to limitations in obtaining realistic maxima voluntary contractions (MVC) in pathological subjects for calibration purposes and in the number of required experimental EMG signals that are difficult to be assessed in neurological conditions (e.g. Parkinson's Disease (PD)). This study aims at verifying the feasibility of introducing EMG-driven NMSM for planning rehabilitation treatments in PD. Thus, a minimal experimental setup compatible with clinics requirements is proposed herein. Four different NMSM were implemented with two different EMG normalization methods and with two different set of experimental EMGs for the muscletendon unit mapping. Results seems promising as no statistically significant differences between the full model and the proposed reduced model were observed.

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D. Torricelli et al. (eds.), *Converging Clinical and Engineering Research on Neurorehabilitation IV*, Biosystems & Biorobotics 28,
https://doi.org/10.1007/978-3-030-70316-5_70

1 Introduction

EMG-driven NMSM can provide important information about the unique anatomical, neurological and functional characteristics of the subjects through the computation of human internal variables, such as muscle activations, muscle forces, and joint moments, from an individual neural signal. These can be used to identify the target of the rehabilitation program or to predict outcomes of different treatments, based on patient-specific characteristics. Despite the potential of adopting these techniques, these models are rarely introduced in clinical practice mainly due to the difficulty of validating the results of muscle forces and the experimental setup and acquisition protocol might result complex and long. Indeed, as it is fundamental to consider restriction due to subjects' physical capacities, people with moment impairments as PD patients, might not bear neither the large numbers of sensors attached to the body, neither the additional trials to perform MVC needed for model calibration purposes.

For this purpose, we proposed in a previous study [1] a minimally invasive setup (reduced) with 4 EMG channels, calibrated through normalized EMG signals with respect of the walking trials (WTNr), to analyze the differences in muscle forces and activations between a healthy court and Parkinson's disease patients. The aim of the present study is to compare the results obtained by WTNr model on a healthy court with the ones obtained by three different implementation of the model in order to detect the impact of various setup on the estimated variables: an MVC trial normalization full setup (MVCTNf) model [2], an MVC trial normalization reduced setup (MVCTNr) model and a WTN full setup (WTNf) model. In order to verify the impact of different NMSM on clinical decision making, results of the current study were compared with the WTNr applied to a cohort of PD subjects [1].

2 Material and Methods

2.1 Participants and Data Collection

Three healthy subjects (age = 60 ± 1 years, BMI = 27.4 ± 4.7 kg/m^2) and 10 PD subjects (age = 66.9 ± 12.8 years, BMI = 27.4 ± 3.6 kg/m^2) have been enrolled for the study. A six cameras stereophotogrammetric system (60Hz, BTS), synchronized with two force plates (960Hz, Bertec) and a 16-channel EMG system (1000Hz, BTS) were used to acquire the data. Two different EMG set up were adopted respectively for the healthy (WTNf), and the pathological ones (WTNr): right limb gluteus maximus and medius, tensor fasciae latae, adductor longus, sartorius, semitendinosus, biceps and rectus femoris, vastus medialis and lateralis, peroneus longus, gastrocnemius medialis and lateralis, soleus and tibialis anterior (WTNf); right and left biceps and rectus femoris, gastrocnemius lateralis, tibialis anterior (WTNr) (Table 1).

Table 1 Mapped musculotendon units

Muscuotendon unit	Experimental EMG Full setup	Experimental EMG Reduced setup
rectfem	Rectus Femoris	Rectus Femoris
vasmed	Vastus Medialis	Rectus Femoris
vaslat	Vastus Lateralis	Rectus Femoris
vasmed	(Vastus Lateralis + Vastus Medialis)/2	Rectus Femoris
bifemlh	Bicept Femoris	Bicept Femoris
bifemsh	Bicept Femoris	Bicept Femoris
semiten	Semitendinosus	Bicept Femoris
semimem	Semitendinosus	Bicept Femoris
latgas	Gastrocnemius Lateralis	Gastrocnemius Lateralis
medgas	Gastrocnemius Medialis	Gastrocnemius Lateralis
sol	Soleus	Gastrocnemius Lateralis
tibant	Tibialis Anterior	Tibialis Anterior

Musculotendon units and the mapping experimental EMG for both full and reduced setups

2.2 Data Processing

Six right foot strikes were selected when the foot was naturally landing on the force plates. Data were processed through MOtoNMS [3], OpenSim and CEINMS [4]. Two different methods were adopted to normalize the healthy subjects EMG signals: the WTN and the MVCTN; while only the WTN was applied on the PD subjects' dataset. In the WTN, the peak amplitude of each EMG linear envelope was computed across all the subject's trials. The MVCTN method consists instead in calculating the maximum EMG value from the MVC acquisition [5]. A generic musculoskeletal model (gait2392 [6]) was used to linearly scale each subjects' geometry in OpenSim. Inverse kinematics, inverse dynamics and muscle analysis tools were used to obtain joint angles and moments, musculotendon moments and moment arms. CEINMS was adopted as toolbox to estimate the muscle activations and forces that best matched the experimental EMGs and joint moments. The implementation of the full setup reflected the one described in [2], while in the reduced setup, only 4 EMG channels were mapped to a total of 12 musculotendon units (Table 1). Two degrees of freedom (ankle plantar-dorsi flexion and knee flexion-extension) were analyzed separately. For each subject 3 dynamic trials were used for the calibration. Then, CEINMS was used to predict the knee and ankle moments, muscle forces and activations with a hybrid EMG-informed model [2].

3 Results

Models accuracy in tracking experimental muscle excitations and moments is reported in Fig. 1. All models accurately represented the estimates of muscle excitations and joint moments. Although WTNr model produced the highest root mean square error (RMSE), statistically significant differences were detected only within the bifemlh activation of the MVCTNf. Both the coefficient of determination (R^2) and the envelope peak position did not show any remarkable difference across the models. Concerning the tracking of the experimental moments significant differences were detected in the swing phase and load acceptance, yet a good model prediction is shown at RMSE and R^2 level. Comparison between healthy and PD subjects showed statically significant differences on muscle forces and joint moments.

4 Discussion

We proposed an EMG-driven NMSM with a minimal experimental setup coupled with a clinically feasible EMG normalization method, and compared with models of enhanced complexity. Statistically significant differences between the four models were not revealed, suggesting that the WTNr might be a valuable tool in muscle force estimation in clinics environment, consistent both at EMG and dynamic levels. Results seem promising in adopting the proposed model in rehabilitation treatment assessment for neuromuscular disorders as PD.

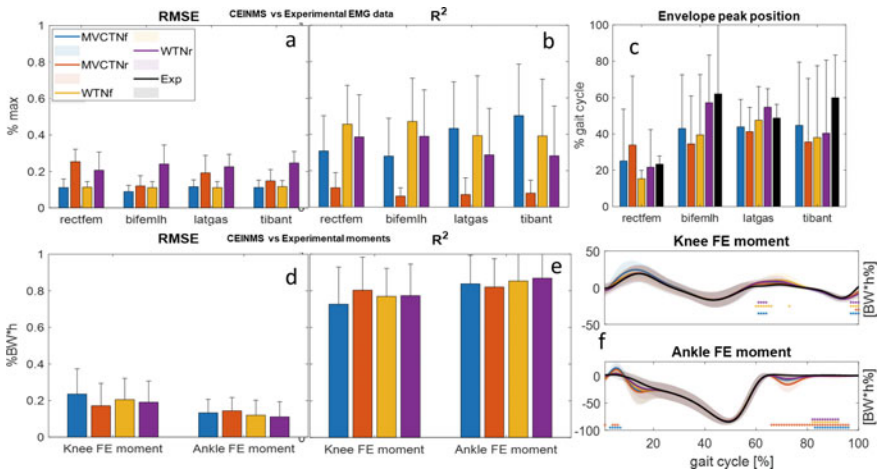

Fig. 1 Comparison between CEINMS models muscle excitations and joint moments versus corresponding experimental data (i.e., EMG envelopes, external joint moments): RMSE (**a** and **d**), R^2 (**b** and **e**), envelope peak position (**c**) and joint moment bands (**f**). Stars indicate statistically significant differences, oneway ANOVA ($P < 0.05$).

5 Conclusion

Even though the loss of information associated with the reduced set up should not be neglected, the current study showed the potential of adopting the quantitative assessment of the forces generated by an activated muscle in the clinical assessment of neurological patients. Further studies are needed to confirm this preliminary results.

Acknowledgements The work was supported by the Fresco Parkinson Institute Italia Onlus.

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