Knee Contact Force Prediction using Electromyograms and Synthesized Key Point Data

Yumei Sun[1,2], Claudio Pizzolato[1,2], Laura E. Diamond[1,2], David J. Saxby [1,2]
[1]Australian Centre for Precision Health and Technology (PRECISE), Griffith University, Gold Coast, Australia
[2]School of Health Sciences and Social Work, Griffith University, Gold Coast, Australia
Email: yumei.sun@griffithuni.edu.au

Summary

We developed and validated a system of sequentially linked neural networks (NN) to estimate lower body kinematics and kinetics as well as knee contact forces (KCF) during walking in individuals with knee osteoarthritis (OA). Further, we assessed the effect of varying the number of electromyograms (EMG) used as input on system accuracy. Results indicate that key point data from computer vision acquisition of human motion can be combined with as few of 4 EMG (medial and lateral gastrocnemius, rectus femoris, and semitendinosus) to estimate KCF with acceptable accuracy (coefficient of determination (R^2)=0.81, root mean squared error (RMSE)=0.64 BW, and normalized RMSE (nRMSE)=18%).

Introduction

Knee OA is musculoskeletal condition that causes pain and reduced function. The KCF is linked to disease pathomechanics and is modifiable treatment target. This study aimed to develop and validate a neural network approach using Bidirectional Long Short-Term Memory neural network (BiLSTM) to estimate lower body kinematics and kinetics as well as KCF during walking in individuals with knee OA.

Methods

This study used a subset of participants from a larger cohort (n=43, 76.6±13.9 kg, 1.74±0.08 m). All participants were diagnosed with mild-to moderate knee OA [1]. The dataset consisted of laboratory-based human movement data (optical motion capture, EMG from 8 major knee-spanning muscles, and ground reaction forces) was modelled using an established OpenSim-CEINMS modelling pipeline to estimate lower limb biomechanics (joint angles and moments, muscle forces and KCF).

From the modelled motion, 10 key points were synthesized to simulate low-fidelity computer vision data and used as input to BiLSTM [2] with a custom Gaussian noise layer applied to the key points to mimic natural noise distribution based on previously reported values [3]. Augmented key points with participant mass, height, and sex were used to first predict lower body kinematics and kinetics. Predicted kinematics and kinetics were then combined with all combinations of 8 EMG (n=255 combinations) to predict KCF. The KCF predictions were evaluated using 10-fold cross-validation with R^2, RMSE, and nRMSE used as performance metrics. Prediction error as a function of EMG number was also analyzed (Figure 1). A regression curve was fitted to the RMSE values across different numbers of EMG. The optimal number of EMG was determined by identifying the point with the minimum Euclidean distance to the lowest RMSE value on the curve. Among the EMG combinations at this optimal number, the combination yielding the lowest RMSE was selected as the best combination.

Results and Discussion

Using 8 EMG, KCF was predicted with average nRMSE 17.55±8.6%, and strong correlation (R^2=0.83). Joint angles and moments were predicted with RMSE 3.50±1.55°and 0.15±0.07 Nm/kg, respectively. The lowest RMSE value on the regression curve corresponds to the 8-EMG (d8), the Euclidean distances from each EMG to d8 range from 62 to 14. The optimal trade-off between sensor number and balancing performance of EMG was determined to be 4 (medial and lateral gastrocnemius, rectus femoris, and semitendinosus), as it exhibited the minimum Euclidean distance (d4 = 14) to d8 (Figure 1).

The NN developed in this study could be deployed in clinics or home using only a small number of EMG combined with a portable computer vision system or ported to IMU. Continued NN development may underpin novel out-of-lab gait retraining interventions that disrupt knee OA progression by optimising knee loads during walking or other activities of daily living.

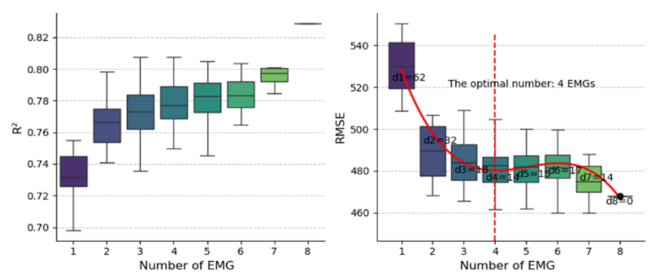

Figure 1: Right: accuracy of different EMG combinations. Left: error of different number of EMG with regression curve and Euclidean distance to the lowest RMSE value on the curve.

Conclusions

The developed neural network predicted KCF and lower body joint angles and moments in individuals with knee OA using synthesized noisy key point and EMG data with acceptable errors. We identified the minimum number and ideal combination of EMG that produce accurate prediction. Findings have important implications for implementation of KCF measurement for people with knee OA in a natural environment (i.e., home, clinic).

References

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