Pressure Insole Data-Driven Model Ensembles for Predicting Knee Mechanics in Female Soccer Athletes

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Summary

Female soccer athletes are inherently more susceptible to anterior cruciate ligament (ACL) injury [1]; however, assessing knee mechanics on the field remains challenging. We explored model ensembles for predicting knee mechanics using pressure-measuring insoles during lateral cutting. All model ensembles exhibited strong to very strong correlations, demonstrating potential for reliable on-field estimations.

Introduction

Preventing ACL injuries in female soccer athletes is essential for performance and health across the lifespan. Given the greater incidence of ACL injuries among females [2], it is necessary to address biomechanical risk factors on the playing field. While laboratory measurements provide detailed insights into knee mechanics during lateral cutting, obtaining the same measurements on the field remains challenging. Therefore, we aimed to build and explore model ensembles for predicting on-field knee mechanics in female soccer athletes using pressure-measuring insoles matched with laboratory kinematics and kinetics during lateral cutting.

Methods

Data were acquired as part of a larger study. Seven competitive female soccer athletes (20.1±1.4 yr; 61±5.3 kg; 168.7±6.0 cm) without ACL injury provided informed consent to participate in this study. Athletes completed six unanticipated cuts in a turfed laboratory using three variations of cleated footwear, both pre- and post-fatigue. Athletes were instrumented with pressure-measuring insoles (Novel Pedar, 100 Hz) while marker coordinates (Vicon, 100 Hz) and ground reaction forces (AMTI, 1000 Hz) were recorded. Mean peak knee flexion angle, valgus angle, internal extensor moment, external valgus moment, and anterior shear force were calculated using inverse dynamics in Visual3D.

Multivariate linear regression model ensembles were generated with DataModeler (Evolved Analytics, LLC) using a complexity-accuracy trade-off. Fifty-five pressure variables were evaluated using genetic programming as potential predictors of each knee mechanics metric. The initial round of modeling generated thousands of unique models which were filtered to identify the "fittest" models: 50% of models with ≤100 complexity score and ≤0.20 square error rate. Pressure variables present in 5% of models were selected for the final round of modeling, where models were restricted to combinations of three variables. The same "fitness" criteria were applied to the final round of modeling, except valgus angle (≤0.30 square error rate). Final model ensembles were selected to maximize the diversity of error residuals.

Results and Discussion

The mean coefficient of determination for model ensembles was 0.84, and the mean complexity score was 77.90 (Table 1). Model ensembles of peak knee valgus angle demonstrated the lowest strength (R^2 = 0.74) and anterior shear force demonstrated the greatest strength (R^2 = 0.91) (Figure 1). These results are similar to those reported in a study using a deep-learning neural network to predict knee valgus moments during walking (R^2 = 0.92) [3], a less complex movement.

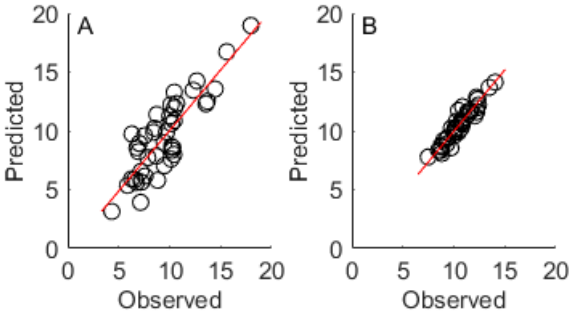

Figure 1: Exemplar correlations in observed and predicted outcomes of A) knee valgus angle (°) and B) anterior shear force (N/kg).

Conclusions

Model ensembles demonstrated strong to very strong predictions of on-field knee mechanics of female soccer athletes using plantar pressure during lateral cutting as input.

Acknowledgments

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References

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Table 1: Characteristics of model ensembles predictive of knee mechanical outcomes related to ACL injury.

	Flexion Angle	Valgus Angle	Internal Extensor Moment	External Valgus Moment	Anterior Shear Force
Models	10	4	9	7	9
Ensemble Variables	4	3	5	4	4
R^2	0.84	0.74	0.86	0.84	0.91
Complexity Score	78	90.25	71.56	89.57	60.11