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REVIEW and EVALUATION

of the PhD Thesis

Landing strategy optimization for lower limb injury risk reduction:

Combining computational biomechanical modeling and machine learning

(by Datao Xu)

1. Structural aspects, formal, quantitative requirements, style

The PhD thesis was written in English language, the composition, the style is logical and understandable. The thesis is well written in English, with minor grammatical errors. The construction, the design of the tables and figures are good with several exceptions, which will be detailed in the comments of the different parts.
The structure follows the regulations of the Doctoral School of Chemical Engineering and Material Sciences from University of Pannonia.
The full length of the thesis is 160 pages (without references list). The dissertation starts with an introduction, research considerations and study justification, objectives. The introduction contains 13 pages (8 % of the work). The thesis has 5 main parts, list of abreviations, tables and figures are added. The number of figures is 69, tables 19. List of abreviations, figures and tables were added.

2. References and publications

The references are edited to the end of the thesis, which are cited from the international literature involving the most relevant research studies, the reference format conforms to regulations of the Doctoral School of Pannonia University.

The list of bibliography contains 242 items, the references in the text are precise and correct.
The candidate lists 21 publications (all with impact factor) related to this Thesis and 19 other publications in english (42 publications in Scopus, h-index 14). The publications are in peer-reviewed international journals with impact factor (Q1, Q2, Q4), in case of 14 publications the candidate is first author.

3. Contextual aspects, topic of the dissertation

The topic of the dissertation investigates the landing, wich is one of many fundamental sports techniques, that can commonly be associated or accompanied by sports injuries, such as anterior cruciate ligament (ACL) injury, lateral ankle sprain (LAS).

The results and conclusions are applicable in the future based on the proposed method for constructing an ACL dynamic load force prediction model. In the future the proposed ACL force prediction model will be combined with a subject-specific musculoskeletal model, and used as an effective and accurate ACL injury risk assessment tool.

The thesis work begins with an overview of the fatigue factor's effect on landing injuries and the specification of the aims and objectives. The author presents *six research questions and six research objectives.*

This study was conducted in the period of two years (from 2022 to 2024) and approved by Ningbo University's Ethics Committee (Approval Number: RAGH20220608). In total 56 healthy male subjects (age: 22.56±5.13 years; body mass: 82.62±13.38 kg; height: 1.85±0.11 m) were recruited for this study.

The analysed thesis provides new insight into human subjects' performance and protection against injuries using machine learning methods to model and predict the complex "input-output" relationship between the biomechanical factors related to the landing in case of sport activities and developed applications for more efficient assisted rehabilitation training.

4. Comments

Scientific comments:

Motivation and goals*:* The topic are up to date, the research questions and goals are clear, and logically connected to each other.

Literature review: Chapters 1.1. to 1.6.: It is a summary overview of the fatigue factor's effect on landing injuries combined with the application of machine learning in predicting lower limb biomechanical variables.

Research methods and validation: For the considered variables this study performed the Paired-samples T-test for the mean value of each sample (112 datasets) to test differences between before-fatigue and after-fatigue. Also, considering the large original datasets (560 original datasets), this study combined machine learning algorithms to determine the recognizability of the two classes of data with each other. A total of 112 samples dataset of each class was randomly distributed uniformly to avoid errors during model training. Meanwhile, the data from the five successful trials for each subject were placed in the same subset during model training to ensure that the model performance was not affected by the same subject's data in different subsets respectively Pearson correlation analysis and linear regression analysis were performed to explore the relationships between them.

For fitness evaluation the K-nearest neighbor (KNN) algorithm was selected as the learning algorithm and an artificial neural network (ANN) model with ten hidden layers was created under the condition of repeated model training and adjustment following the actual datas.

To evaluate the results the Statistical Parametric Mapping (SPM) method was used and for the implementation of SPM, the open-source MATLAB script (paired-samples T-test) of One-Dimensional SPM (SPM 1D) was employed to test the statistical differences, and the significance threshold was set as 0.05. Data analysis was conducted in SPSS 27.0 (IBM Corporation, NY, USA).

5. Concerning the specific questions and remarks made at the workshop defense, the final Thesis contains the following corrections:

5.1 References in case of **Figures 1** to **8**. (in the text or after figure name)

5.2 „the linear envelope of the collected EMG raw signal was band-pass filtered with a Butterworth fourth-order filter in the frequency range of 10-400 Hz” (§ 2.2.3, page 22) – reference [156].

The following correction proposals are not implemented in the final version of the Thesis:

5.3 The § 2.3.4 Statical evaluation – presents the aspects of the used statistical evaluation method, maybe you change the title in statistical evaluation.

5.4 The § 2.3.5 Clinical evaluation is very general – please specify more details of this aspect. (reference publications - research projects or clinical evaluation report aspects or criterias)

5.5 Thirty male subjects were recruited (Age: 24.4±4.2 years; Height: 176.2±6.4 cm; Body Mass: 75.6±8.4 kg) in case of the research objective 4 - § 2.5, page 43, the total subjects number was 56 males (§ 2.2.1, page 19). The criteria for subject screening were: (1) no history of severe surgery within the previous six months; (2) no other injury variables that would affect the study; (3) no additional factors that would affect athletic performance.

5.6 Data analysis was conducted in SPSS 27.0 (IBM Corporation, NY, USA) - § 2.4.5, page 41, Analysis of variance (ANOVA) was performed in SPSS 24.0 (SPSSs Inc., Chicago, IL, USA) - § 2.5.6, page 53, - please specify why you are using different SPSS software versions.

5.7. **Results - Figure 23, Figure 29, Figure 31 – 33, Figure 54 - 61** – in the printed version the diagramms are difficult to read and evaluate.

5.8. Mistype: „sampling frequencies were sampled at 200hz, 1000hz" - page 63 (Hz)

5.9 Please give the abreviation for AIC (ex: § 3, page 71, and § 4, page 123), – or is it the mistype of AICA?

6. Research objectives and Thesis points:

The research questions, objectives and the obtained results are clearly presented in the § 1.7 Aims and objectives respectively in the Abstract section of the Thesis.

The candidate established **six research objectives,** wich were achieved in the **six Thesis points** as follows:

- calculate anterior cruciate ligament (ACL) internal dynamic load forces by constructing a *musculoskeletal modeling*. In addition, this study aims to explore whether there are detectable and recognizable differences in ankle joint kinematics, lower limb joint energy dissipation (joint work) and ACL load force between before-fatigue and after-fatigue

landing, as well as to explore the possible relationship between them, achieved by the **1st Thesis point**,

- investigate whether explainable machine learning (XML) can help with landing pattern recognition and to what extent it can aid in the interpretation of prediction results, achieved by the **2nd Thesis point**, (Fig. 65 difficult to read and evaluate)
- more realistically revert and simulate the ACL injury mechanics, proposing also an optimized landing strategy that can reduce the injury risk, achieved by the **3rd Thesis point**.
- explore the effects of different ankle plantarflexion angles during single-leg landing (SL) on knee impact loading and ACL injury risk, achieved by the **4th Thesis point**.
- develop a highly accurate and easy-to-implement ACL dynamic load force prediction model by combining deep learning and the explored relationship between ACL force and ankle motion pattern, achieved by the **5th Thesis point**.
- develop a movement intention detection technology for estimating each joint continuous kinematic variable based on the lower limb muscle synergy pattern, developing applications for more efficient exoskeleton-assisted rehabilitation training, achieved by the **6th Thesis point**. (Fig. 69 difficult to read and evaluate)

General remark on the Thesis points:

Separation of the Thesis points from the conclusions related to them.

In case of the proposed **Thesis points,** reorganisation of the text, in order to higlight the obtained general applicable results from the obtained experimental results. (First the general applicable Thesis point and followed by the experimental results, figures and related articles wich sustains the Thesis point)

The proposed Thesis points can be accepted.

7. Conclusions:

The topic of the thesis investigated the landing pattern differences between before-fatigue and after-fatigue single-leg landing (SL), as well as explored the relationship between ankle initial contact angle (AICA), ankle range of motion (AROM) and peak anterior cruciate ligament force (PAF), lower limb joint energy dissipation.

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The current findings revealed that the use of larger ankle plantarflexion angles during landing may be an effective solution to reduce knee impact load and the risk of rupture of the medial femoral attachment area in the anterior cruciate ligament.

Future research directions may include the combination of the proposed method for constructing an anterior cruciate ligament (ACL) dynamic load force prediction model with a subject-specific musculoskeletal model, and used as an effective and accurate ACL injury risk assessment tool.

New scientific results are presented in the evaluated PhD dissertation, these new findings are sustained by the six proposed Thesis points and by journal papers (42 publications in Scopus, h-index 14). The publications are in peer-reviewed international journals with impact factor (Q1, Q2, Q4), in case of 14 publications the candidate is first author.

I recommend the acceptance of this PhD Thesis for final defense.

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Szombathely,

2025.06.10

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