Gait Event Identification in Healthy and Pathological Gait Using Kinematics and Machine Learning Models

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Summary

In this study, we investigated gait event detection in healthy groups using kinematics-based computational models and machine learning approaches. Seven kinematics-based methods and one Long short-term memory (LSTM) model were evaluated, focusing on the prediction accuracy of heel strike and toe-off events. Our findings have the potential to enhance gait analysis and improve the detection of gait events in diverse populations. This could contribute to advancements in clinical applications, rehabilitation practices, and the development of assistive exoskeletons.

Introduction

Gait event detection is a fundamental component of gait analysis, ensuring precise identification of key moments within the gait cycle. Both kinematics-based computational models and deep learning models have been widely used in gait event detection. Despite significant progress in this field, few studies have compared the performance of these methods across different data centers and subject populations while employing both approaches simultaneously. Our objectives are twofold: (1) to identify heel strike and toe-off events in both healthy and pathological groups using kinematics-based and LSTM models, and (2) to evaluate the generalizability of these models across different collection centers and subject groups.

Methods

A total of 4363 gait cycles at self-selected walking speed from 588 able-bodied subjects (age: 45 ± 16.2 years; sex: 317F/271M; weight: 62.7 ± 13.5 kg; height: 164.4 ± 9.1 cm) were collected [1]. Marker trajectories and ground reaction force (GRF) were recorded (Miqus M3 Qualisys, AMTI force plates). The GRF was used to identify heel strike and toe-off events using a 20 N threshold, serving as the ground truth for both kinematics-based and machine learning models.

Seven kinematics-based methods for gait event identification were evaluated: Foot Trajectories Relative to the Pelvis (Zeni et al., 2008), High-Pass Filtered Foot Markers (Desailly et al., 2009), Foot Marker Velocity Extremes (O'Connor et al., 2007), Foot Marker Velocity Threshold (Ghoussayni et al., 2004), Foot Marker Acceleration Extremes (Hreljac et al. 2000 and Hsue et al., 2007), and Position and Velocity Combined (Bonci et al., 2022).

LSTM models were constructed to identify gait events using the position, velocity and acceleration of pelvic, heel and toe markers (including LASIS, LPSIS, LFCC, LFMT2, RASIS, RPSIS, RFCC and RFMT2), as well as the heel position relative to the pelvis as input. Gait events were detected from the output probabilities using a peak detection algorithm with a threshold of 0.01, as proposed by Lempereur et al. [2].

Results and Discussion

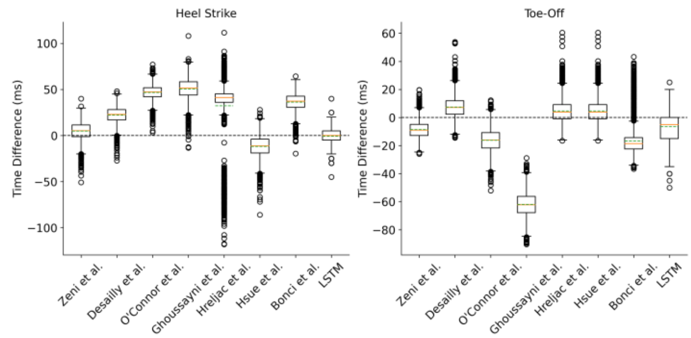

Figure 1: Prediction errors of heel strike and toe-off events using kinematics-based methods and LSTM models.

The Zeni et al. method demonstrated the highest prediction accuracy among kinematics-based approaches, likely due to the alignment between its normative dataset and the intended application. Velocity threshold-based methods required careful tuning of thresholds across different datasets to maintain accuracy. Acceleration-based methods showed good predictive accuracy for horizontal components but were less accurate for vertical components, which appeared to depend on individual walking patterns. Meanwhile, LSTM models achieved high predictive accuracy for both heel strike and toe-off events, highlighting their effectiveness.

Conclusions

Kinematics-based methods, particularly position- and acceleration-extreme-based approaches, demonstrated robust accuracy. In contrast, velocity-threshold-based methods require careful tuning for different datasets. However, this study only tested the methods on a normative dataset due to time constraints. Further investigation is underway to evaluate these methods in populations with post-stroke conditions and knee osteoarthritis, assessing the generalizability of these models across various data collection centers and diverse subject groups.

Acknowledgments

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References

[1] Liang P. et al. (2020). *Sci. Data*, **7**: 1-13.
Lempereur M. et al. (2020). *J. Biomech.* **98**:1-4.