From treadmill to outdoor walking: enhancing ground contact timing prediction in older adults using transfer learning

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Summary

Accurately identifying ground contact timings (GCT) is essential for evaluating mobility and fall risk in older adults. While treadmills provide controlled data collection, they lack real-world gait variability. This study investigated the generalizability of deep learning models trained on treadmill walking data from young adults to treadmill and outdoor walking data from older adults to detect GCT. Data were collected using foot-mounted IMUs, with ground truth derived from pressure insoles and motion capture. Three models were tested, with transfer learning applied iteratively to fine-tune models with older adults' data. The convolutional neural network outperformed other models, achieving F1-scores of 0.986 for treadmill and 0.912 to 0.964 for outdoor terrains. Transfer learning improved predictions, plateauing with 10 treadmill and 5 overground participants. Decline walking posed challenges due to its unique biomechanics.

Introduction

Accurate identification of ground contact timings (GCT) is crucial for assessing mobility, gait asymmetry and fall risk in older adults [1]. Treadmills offer prolonged data collection but fail to capture real-world gait variability. Combining deep learning models with wearable inertial measurement units (IMUs) offers a scalable solution, though generalizing these models to unseen data, particularly overground walking, remains challenging.

This study evaluated the generalizability of deep learning models trained on treadmill walking data from young adults to treadmill and outdoor walking data from older adults. Additionally, we investigated whether transfer learning can improve predictive accuracy of GCT.

Methods

Foot-mounted IMU walking data was collected from 20 young adults (27.62 ± 4.41 years) on treadmills and 26 older adults (75.96 ± 5.22 years) on treadmills and outdoor level, incline, and decline terrains at comfortable, self-selected speeds [2]. Ground truth GCTs were derived using pressure insoles (young adults) and manually-annotated motion capture (older adults). A fully connected neural network, a convolutional neural network (CNN), and a bidirectional long short-term memory network were trained on IMU data from younger adults (23900 steps). Transfer learning was applied incrementally (n=1, 5, 10, 15, 20) by fine-tuning the best-performing model with a) treadmill walking and b) overground level walking from older adults. Model performance was evaluated on unseen outdoor data from 6 older adults using F1-score.

Results and Discussion

After fine-tuning, the CNN outperformed other models, achieving the highest F1-scores: 0.986 for treadmill, 0.964 for outdoor level, 0.954 for incline, and 0.912 for decline walking. Transfer learning with older adults' treadmill data improved F1-scores, plateauing at 10 participants. Fine-tuning with overground data further enhanced performance, with scores plateauing at five participants (Figure 1). However, decline walking consistently exhibited lower F1-scores due to its unique biomechanical demands.

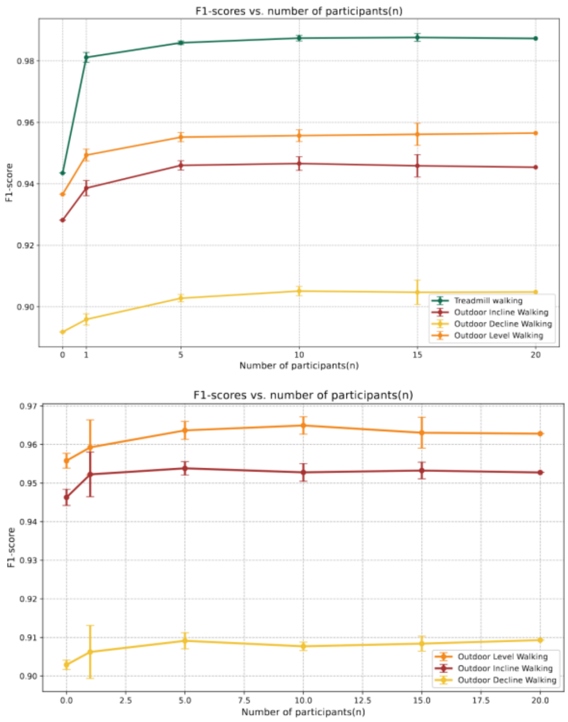

Figure 1: Results of iteratively fine-tuning models using (a) treadmill data and (b) overground level data, showing the impact on F1-scores. Baseline values at n=0 represent the performance before fine-tuning.

Conclusions

This study demonstrated that the CNN model trained on treadmill data from young adults can be effectively adapted to older adults' outdoor walking using transfer learning. The model's ability to generalize highlights the utility of combining IMU data with incremental fine-tuning to reduce reliance on extensive datasets from target populations. Lower performance on decline walking indicates a need for specialized modeling strategies to address unique biomechanical and environmental challenges. These findings emphasize the potential of transfer learning to enable real-world gait monitoring for older adults.

References

[1] Ruiz-Ruiz L et al. (2021). *Sensors*, **21**: 6918.

[2] Matikainen-Tervola E et al. (2024). *Gait Posture*, **114**: 277–283.