Research Square

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Hidden Markov Model based Stride Segmentation on Unsupervised Free-living Gait Data in Parkinson's Disease Patients

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Research

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Abstract

Background: To objectively assess a patient's gait, a robust identification of stride borders is one of the first steps in inertial sensor-based mobile gait analysis pipelines. While many different methods for stride segmentation have been presented in the literature, an out-of-lab evaluation of respective algorithms on free-living gait is still missing. Method : To address this issue, we present a comprehensive free-living evaluation dataset, including 146.574 semi-automatic labeled strides of 28 Parkinson's Disease patients. This dataset was used to evaluate the segmentation performance of a new Hidden Markov Model (HMM) based stride segmentation approach compared to an available dynamic time warping (DTW) based method. Results: The proposed HMM achieved a mean F1-score of 92.1% and outperformed the DTW approach significantly. Further analysis revealed a dependency of segmentation performance to the number of strides within respective walking bouts. Shorter bouts (<30 strides) resulted in worse performance, which could be related to more heterogeneous gait and an increased diversity of different stride types in short free-living walking bouts. In contrast, the HMM reached F1-scores of more than 96.2% for longer bouts (>50 strides). Furthermore, we showed that an HMM, which was trained on at-lab data only, could be transferred to a free-living context with a negligible decrease in performance. Conclusion: The generalizability of the proposed HMM is a promising feature, as fully labeled free-living training data might not be available for many applications. To the best of our knowledge, this is the first evaluation of stride segmentation performance on a large scale free-living dataset. Our proposed HMM-based approach was able to address the increased complexity of free-living gait data, and thus will help to enable a robust assessment of stride parameters in future free-living gait analysis applications

Full Text

This preprint is available for download as a PDF.

Figures

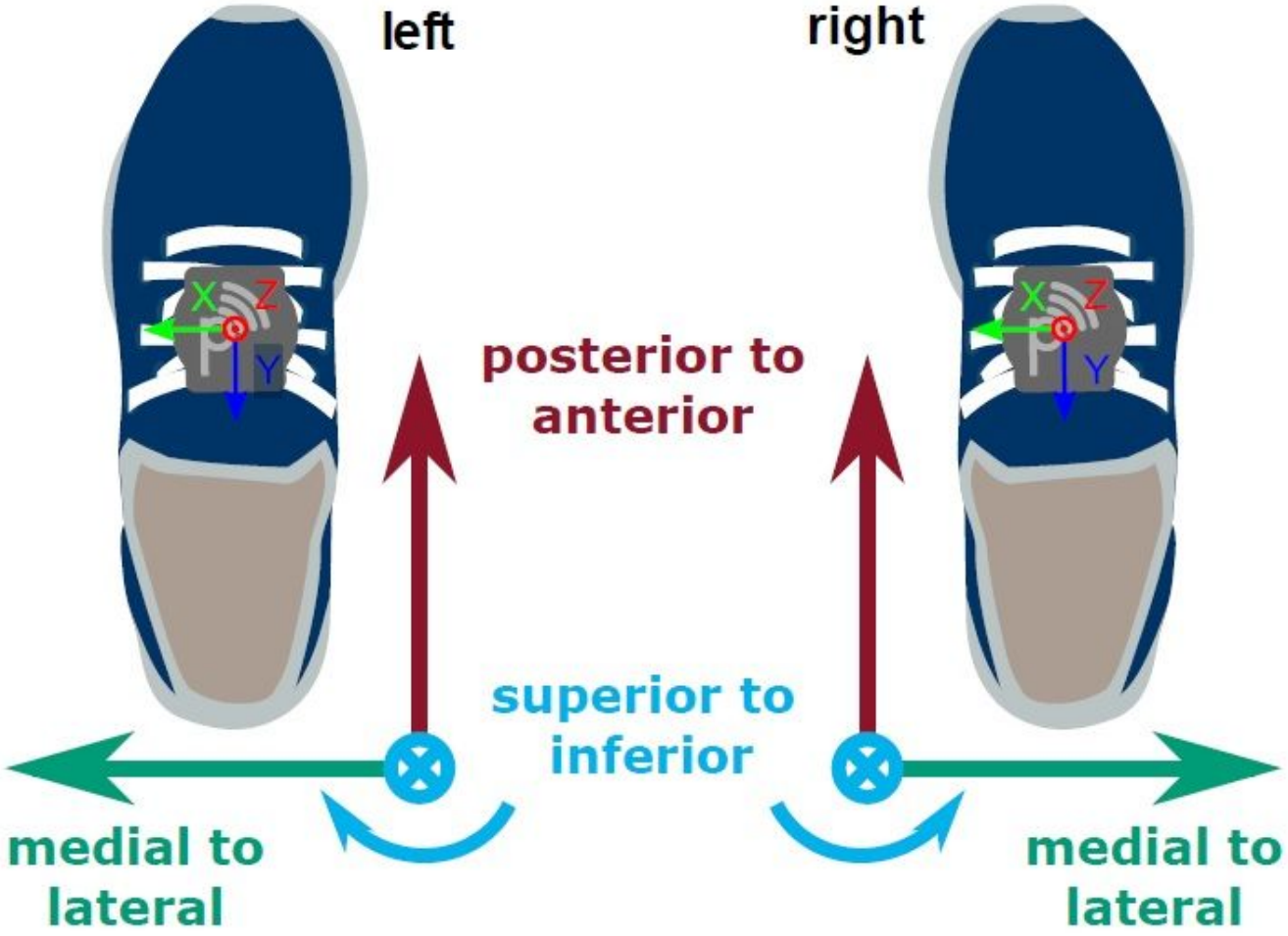


Figure 1

Shoe-/ body-frame coordinate system denition with IMU sensors attached to the instep position of the shoes.

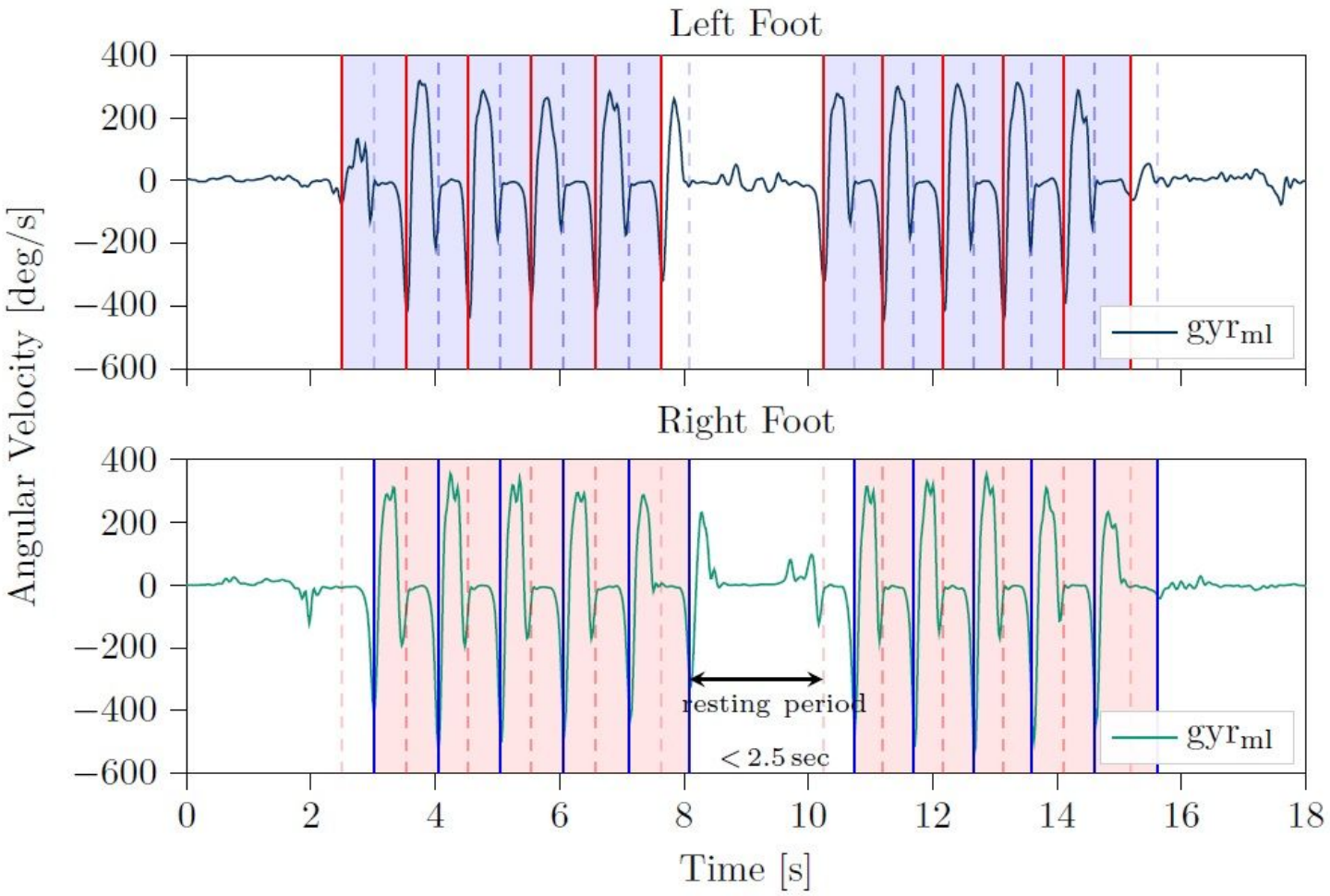


Figure 2

Example data of one walking bout with 20 manually annotated strides and a maximum resting period of 2.5 s. Solid lines represent semi-automatically labeled stride borders, while dashed lines correspond to the borders of the opposite foot.

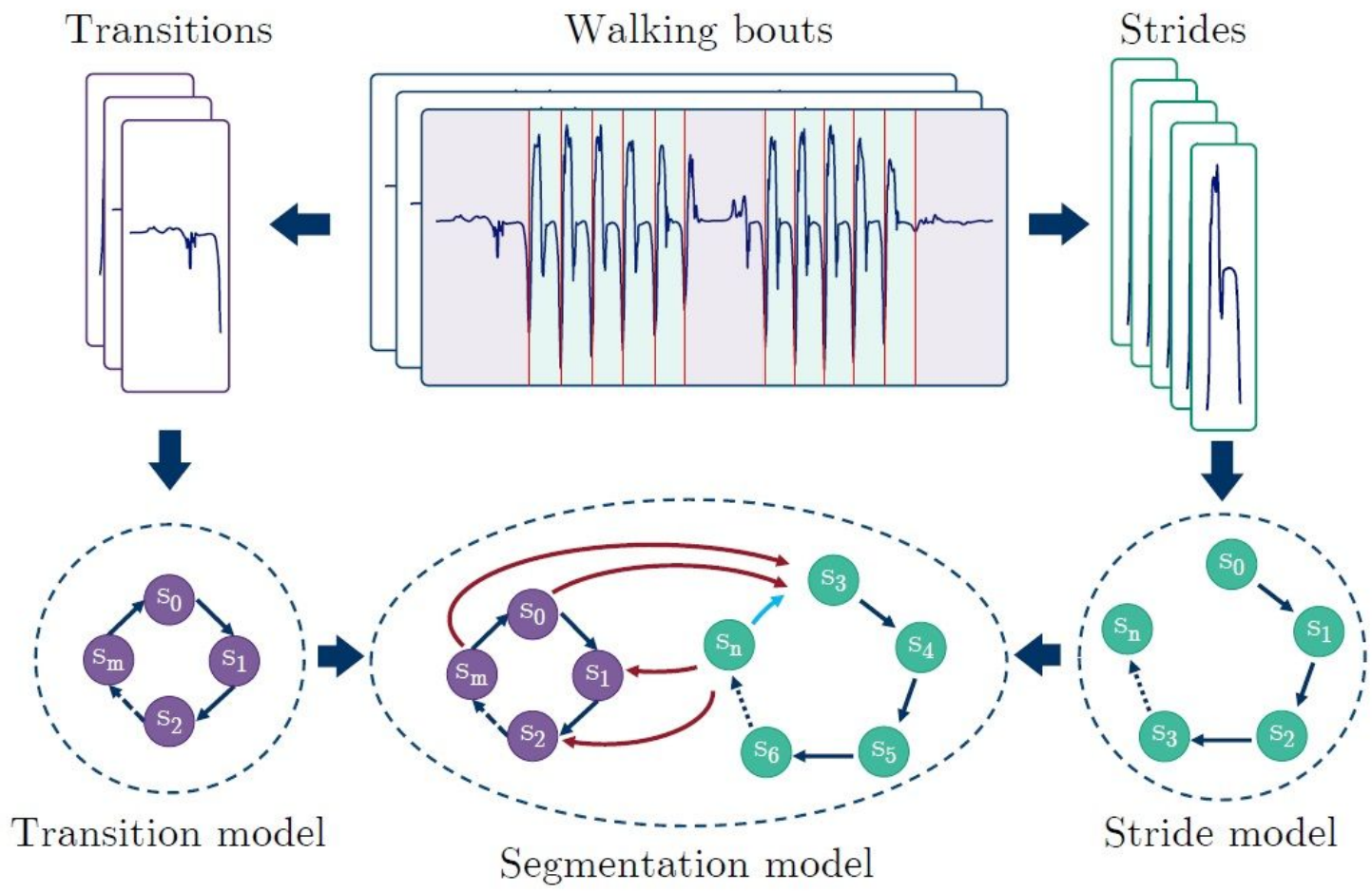


Figure 3

Schematic of a two-class HMM: The transition model and the stride model were trained separately on the respective parts of the training dataset. In a second step, the missing edges were calculated based on the complete training set to connect both models.

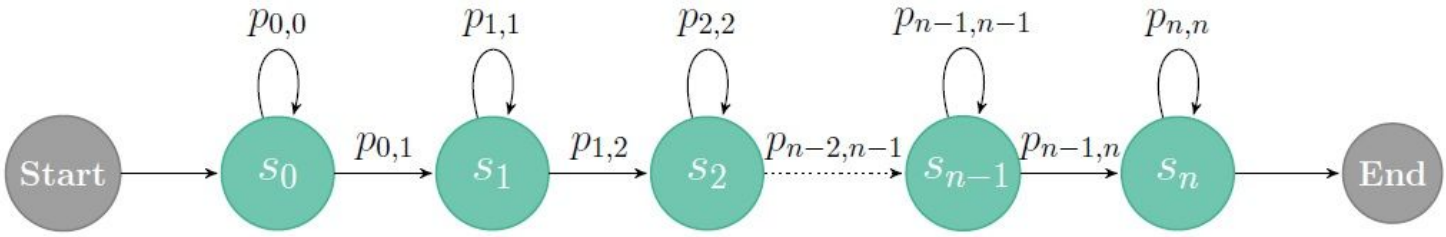


Figure 4

HMM structure of the stride sub-model: A left-right Markov chain from state s0 to sn, with transition probability pn;n+1, and self transition probability pn;n. The sequence is enforced to always start with state s0 and end with sn.

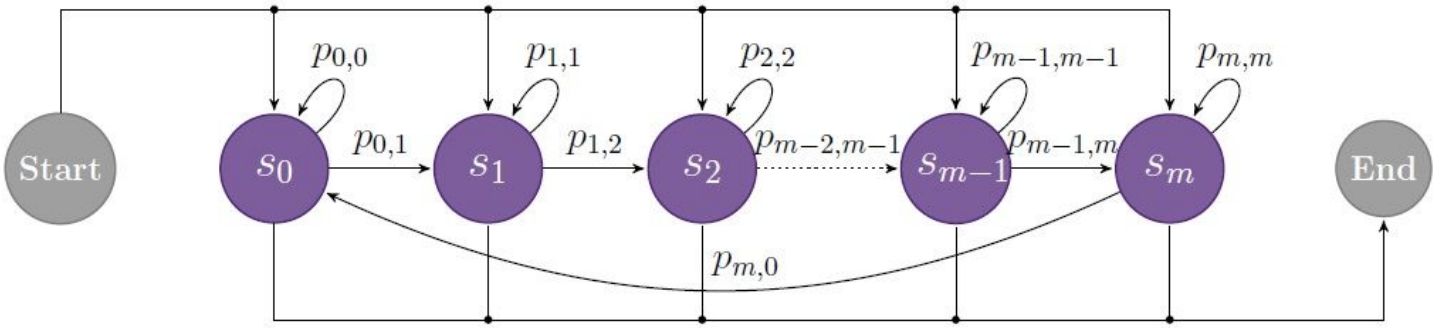


Figure 5

HMM structure of the transition sub-model: A left-right Markov chain from state s0 to sm, with transition probability pm;m+1, and self transition probability pm;m. Additionally, a transition from sm to s0 was added. Sequences may start and end from any state.

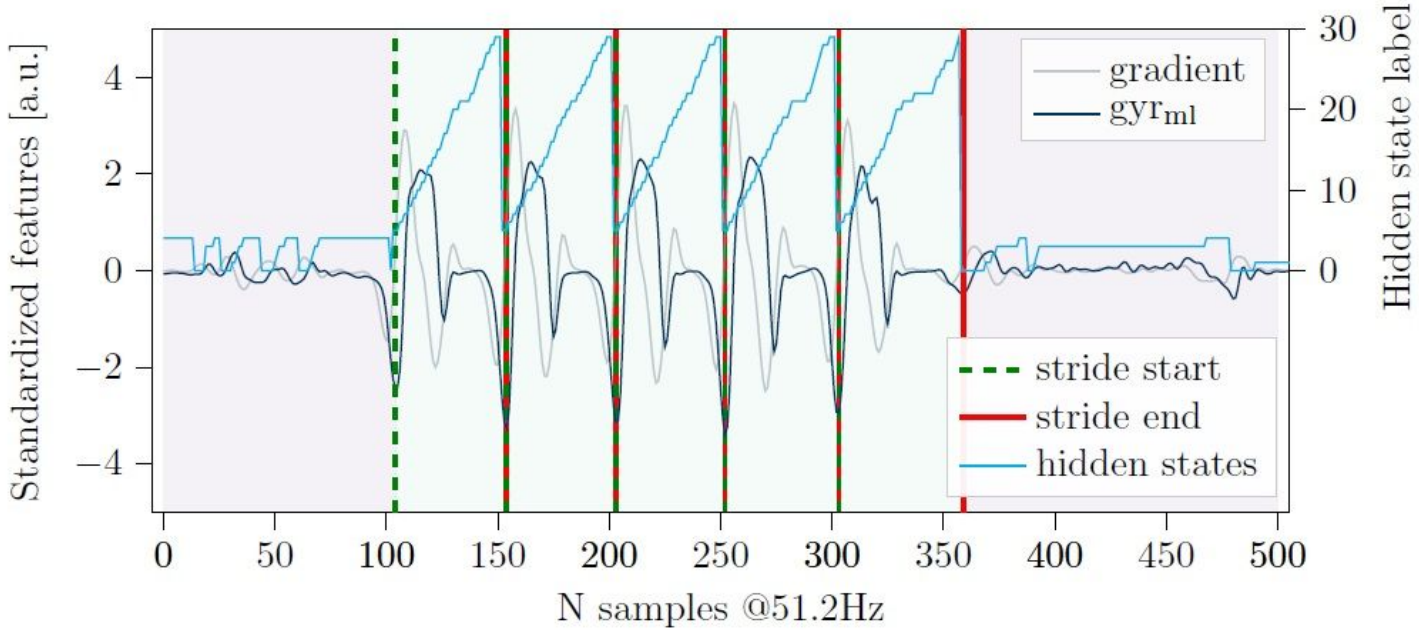


Figure 6

Input signal of a walking bout with predicted hidden state sequence and derived stride borders. States 0 to 4 represent transitions, while states 5 to 29 refer to the stride model.

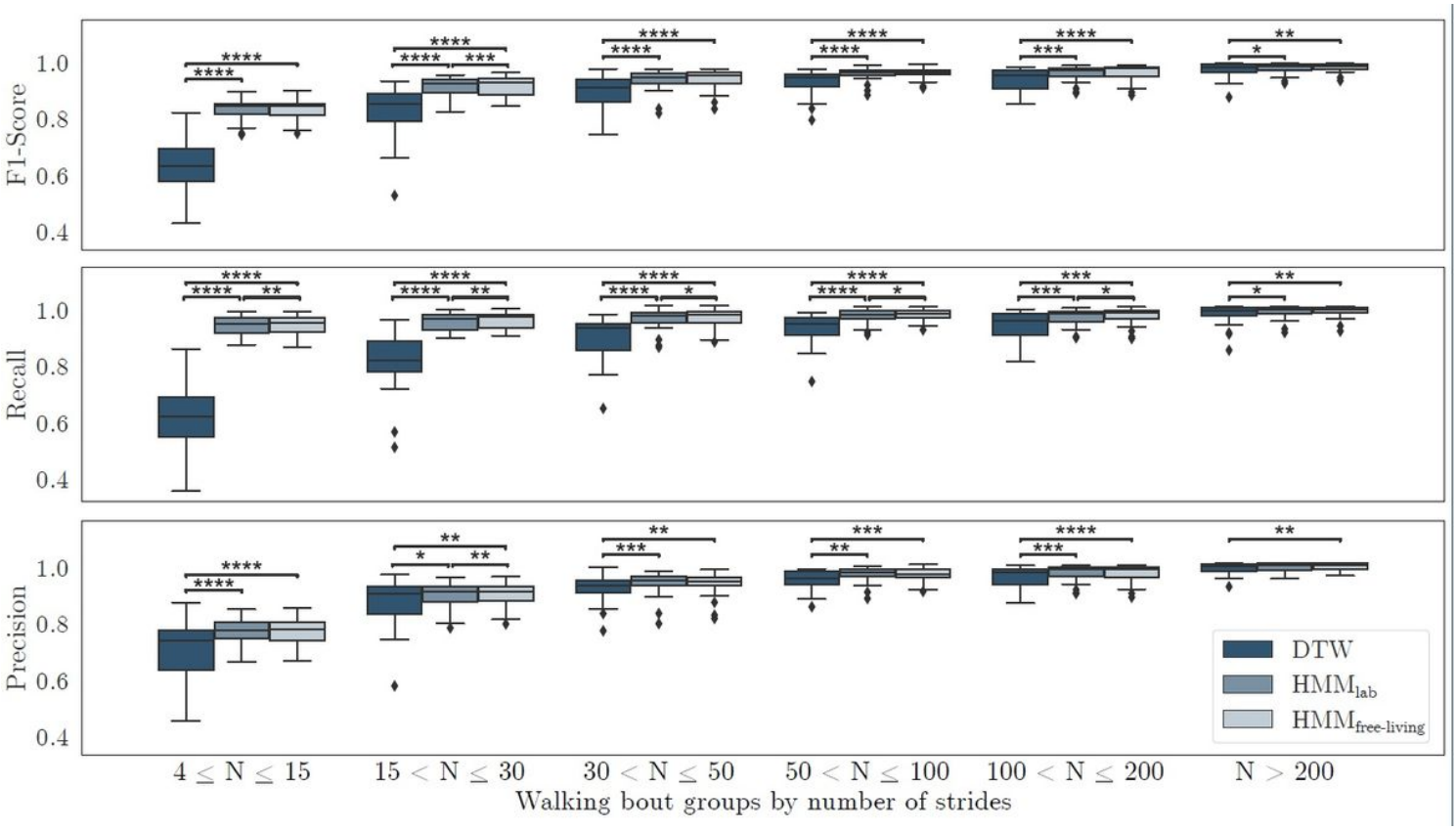


Figure 7

Segmentation performance on the free-living dataset, grouped by the number of strides per walking bout. Signicant differences between methods were identied using paired t-tests with *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$ and ****: $p < 0.0001$.

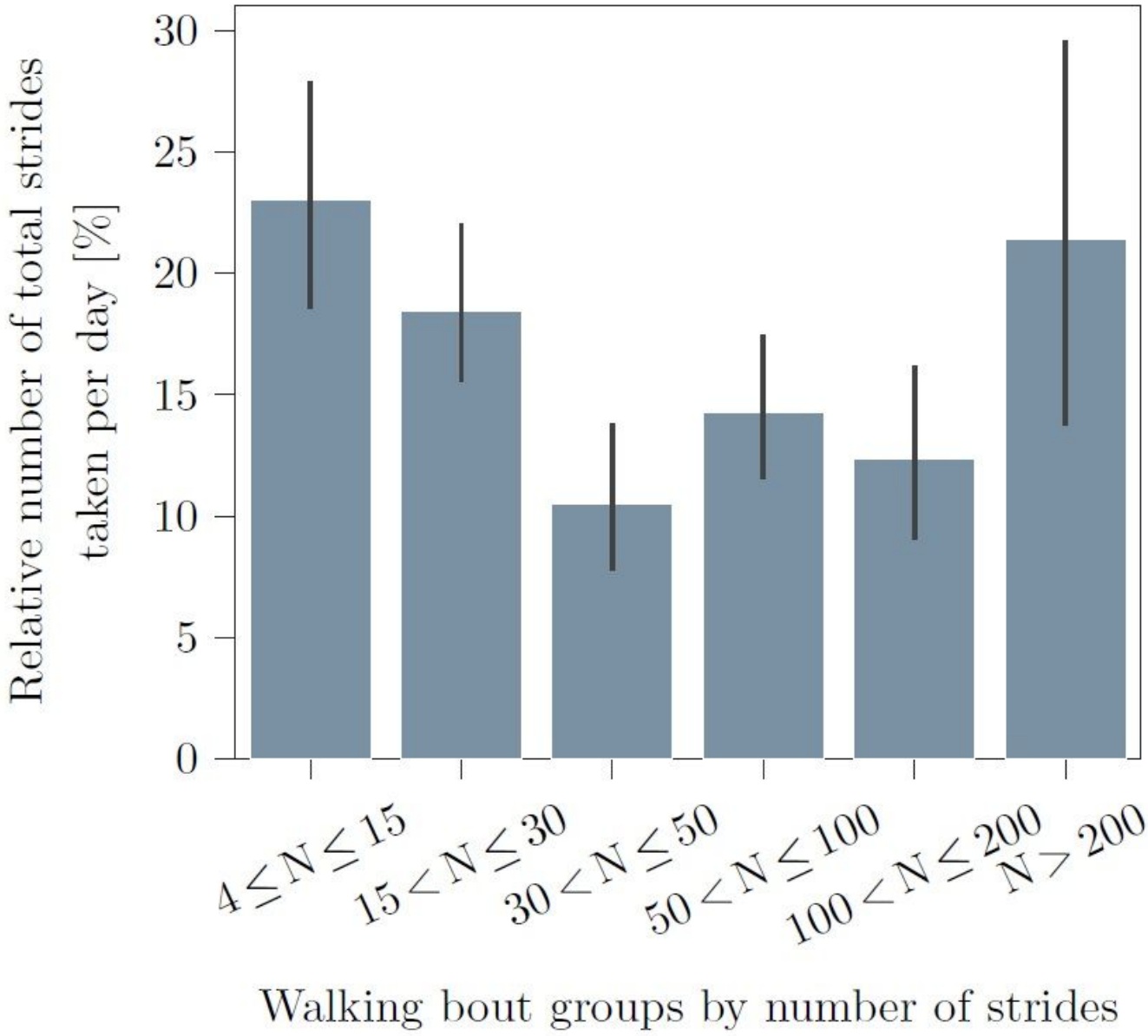


Figure 8

Distribution of the relative number of strides per day for the complete patient cohort. Bars represent the mean and the standard deviation per bout group.

Supplementary Files

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