Segmented Gait Analysis Using Pressure-Sensing Insoles in a Hemiparetic Patient: A Case Study

Tomoko Funayama [1)] ,
Yasutaka Uchida [2)] , Eiichi Ohkubo [2)] , Ryota Kimura [3)]

1) Dept. of Occupational therapy, Teikyo University of Science, Uenohara-shi, Yamanashi, Japan,
e-mail: funayama@ntu.ac.jp
2) Dept. of Life Science, Teikyo University of Science, Adachi-ku, Tokyo, Japan.
3) Dept. of Rehabilitation, Seirei Yokohama Hospital, Yokohama-shi, Kanagawa, Japan.

Profile

Tomoko Funayama

- Research focus: use of digital wearable devices to support people with disabilities, in collaboration with engineering specialists.
- Experience as an occupational therapist: providing therapy for disabled and older people in hospitals, nursing homes, and their homes.
- Current affiliation: Department of Occupational Therapy, Faculty of Medical Sciences, Teikyo University of Science.

INTRODUCTION / PURPOSE

- Recent wearable advances enable detailed biomechanical data. Continuous gait monitoring is possible through footwear-integrated insoles.
- Gait includes straight walking and variable phases—turning, stepping, stopping, and swaying—particularly challenging for those with impairments. Analyzing the full walking period uniformly may obscure key characteristics.
- This study proposes a novel method by segmenting smart insole data into straight and irregular walking phases, demonstrated in a case study with 4 regions per sole (8 total) in a stroke hemiparetic patient.

EXPERIMENTAL METHOD – OVERVIEW

- Devices and Software
- Participant and Measurement Method
- Gait Characteristics and Analysis Method
  - Calculation of Stride Time
  - Method for Segmenting Insole Data
  - Calculation of Mean Values
  - Mean of Peak Values
  - Calculation of Decline Rate

DEVICES AND SOFTWARE

- **Smart insole:** FEELSOLE® (Toyoda Gosei Co., Ltd.)
  - 4 pressure sensors per sole (toe, heel, inside, outside)
  - Sampling frequency: 50 Hz
  - Calibration: no load, both feet, left foot, right foot
  - Data via ORPHE TRACK® app → Cloud → CSV

- **Gait-assistive robot:** Orthobot® (FINGGAL LINK Inc.)
  - Attached to KAFO (knee–ankle–foot orthosis)
  - Guides lower limb toward desirable walking pattern

PARTICIPANT AND MEASUREMENT

- Rehabilitation: Began the day after stroke, five days a week. Gait was assessed on day 16 with a smart insole and gait-assist robot
- Participant: Single male, 70s, hospitalized for post-stroke rehabilitation
- Gait assessment: Conducted under three conditions
  - Before using the gait-assistive robot
  - During use of the gait-assistive robot
  - After removal of the gait-assistive robot
- Medical status: Stroke with left hemiparesis, with a history of traumatic brain injury and femoral neck fracture
- During assessment:
  - Participant unable to walk independently; therapist provided support from behind
  - Robot attached to left lower limb
  - Task included straight walking and a U-turn

CHARACTERISTICS AND ANALYSIS METHOD

- Gait Characteristics and Data Processing
- Excluded first and last 100 data points
- Compared patient gait with healthy controls:
  i. Peak/trough values fluctuated, lacked consistency
  ii. Irregular peak shapes; occasional “M-shaped” waveform
  iii. Inconsistent stride times
  iv. Reduced inside/outside pressures on right foot
  v. Pronounced left–right asymmetry
  vi. No distinct peaks during turning (irregular gait)
- Wide variation in peak amplitudes → single threshold impractical
- Dataset segmented to exclude prolonged stride durations
- Analysis focused on straight walking periods

Segmentation Method

Calculation of Stride Time

- Peaks sometimes appeared in rapid succession or irregular forms
- Applied moving average (window size = 11) to smooth data
- Stride time = interval between two successive heel peaks (left or right)

Method for Segmenting Insole Data

- Mode of stride times calculated from smoothed data
- Irregular gait (turning, interruptions) ⟶ excluded
- Segmentation steps:
  - Calculation of Modal Stride Time
    - Stride = interval between peak x and x+1
    - Threshold for peak detection: $Thresh\_peak = Min + (Max - Min) \times 0.125$
    - Time bins (0.2 s increments); most frequent bin (right heel) = modal stride time
  - Exclusion of irregular gait
    - Irregular gait (> 1.1 × modal stride time) removed
    - Buffer = ¼ median stride time (right heel) at start/end
    - Longest straight-walking segment used for analysis

Calculation of Mean, Peak, and Decline Rate

Calculation of Mean Values

- Mean values calculated for each insole region
- Based on both nonsegmented and segmented raw data

Mean of Peak Values

- Peak values = maximum force at heel, toe, inside, and outside regions
- Calculated for both nonsegmented and segmented data.
- Extracted for each foot-ground contact

Calculation of Decline Rate

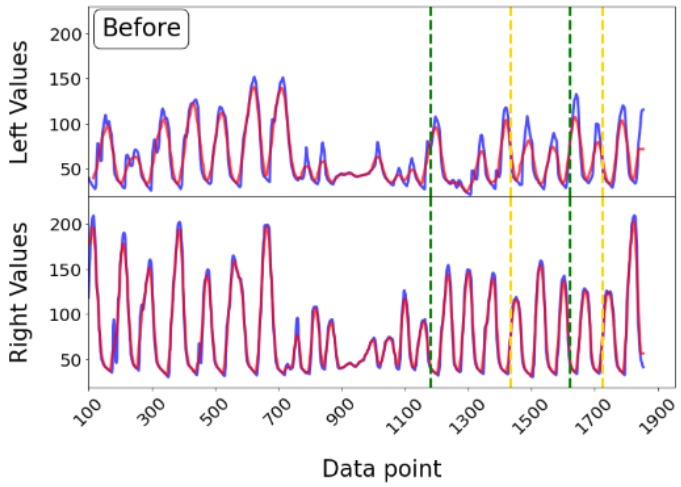
- Decline rate = decrease in pressure after each peak
- Defined as difference in weighted averages at x and x+1 Weighted average
  5 points: Target point 40%, neighbors 20% each, secondary neighbors 10% each
- Maximum decline rate per contact extracted and averaged

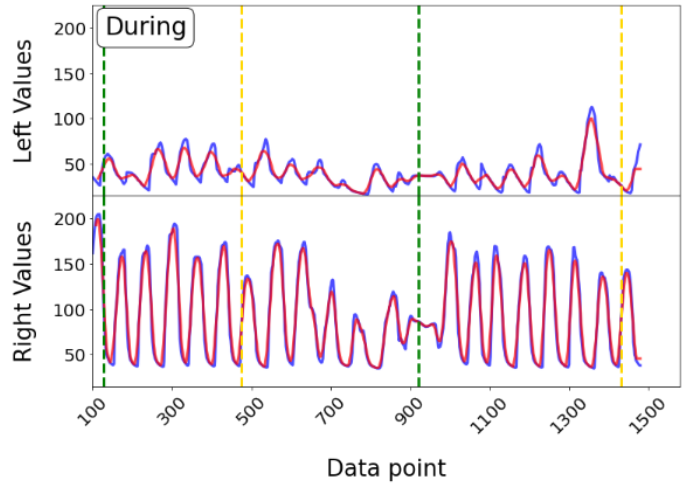
RESULTS

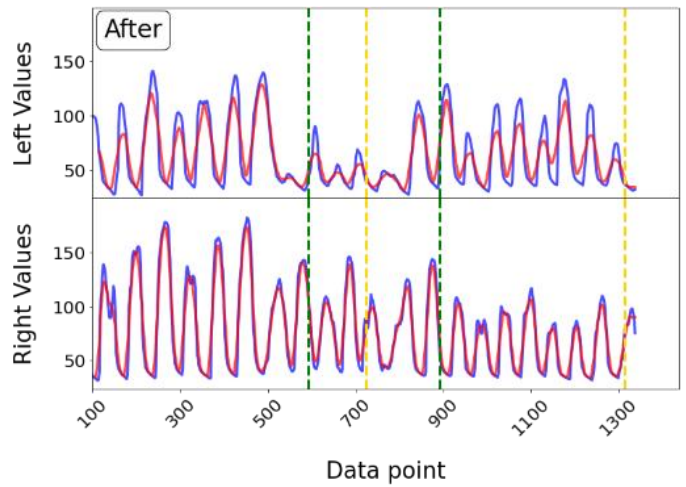
- Data Segmentation
- Stride Time
- Mean Values
- Mean Peak Values
- Decline Rate

Data Segmentation

- Irregular time segments excluded
- Longest and second-longest walking durations identified
- Figure : Walking data before, during, and after robot use
  - Green lines = start times of straight walking segments
  - Yellow lines = end times of straight walking segments

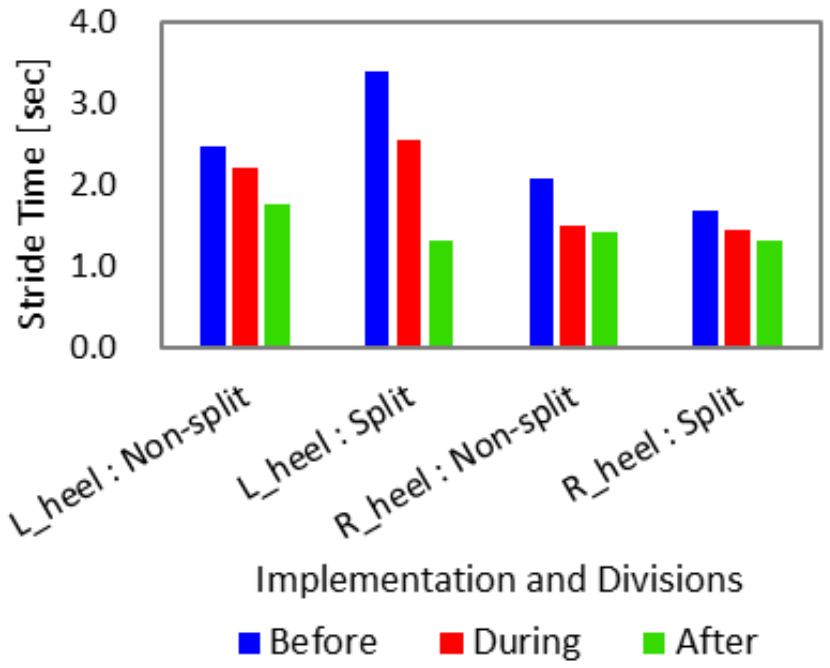






Stride Time

- Average stride times calculated from heel peaks (left & right)
- Results shown for segmented (“split”) and nonsegmented (“non-split”) data



Average stride time from split and non-split data.

Findings:

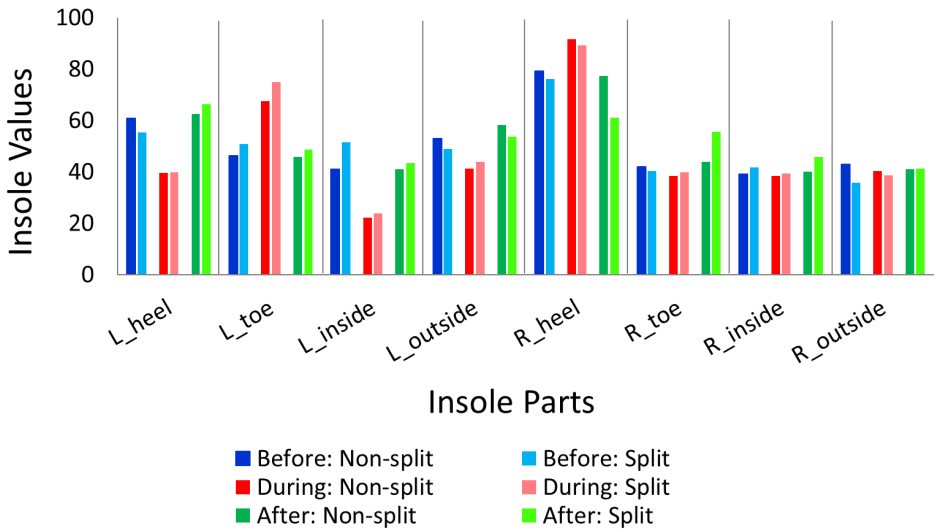
- Left stride time was longer than right (better-functioning side)
- After robot removal: stride times decreased, left–right difference was reduced (notably in split data), and a large discrepancy was observed between split and non-split data for the left heel
- Stride time asymmetry was greatest before robot use, particularly in split data

Mean and Mean Peak Values

- Results shown for segmented (“split”) and nonsegmented (“non-split”) data
- Mean values and mean peak values showed similar trends with some differences

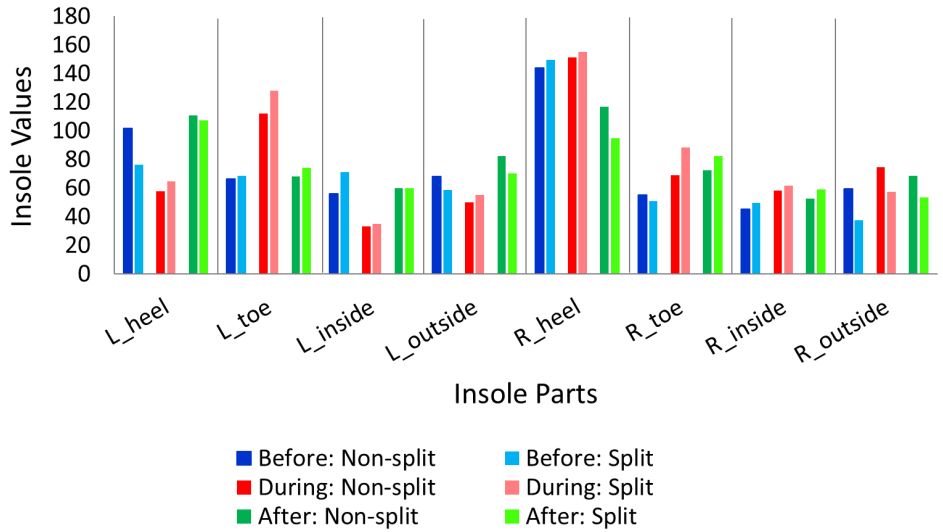
Mean values

- After robot removal:
  - Right heel mean decreased in split data
    → reduced asymmetry
  - Right toe mean increased



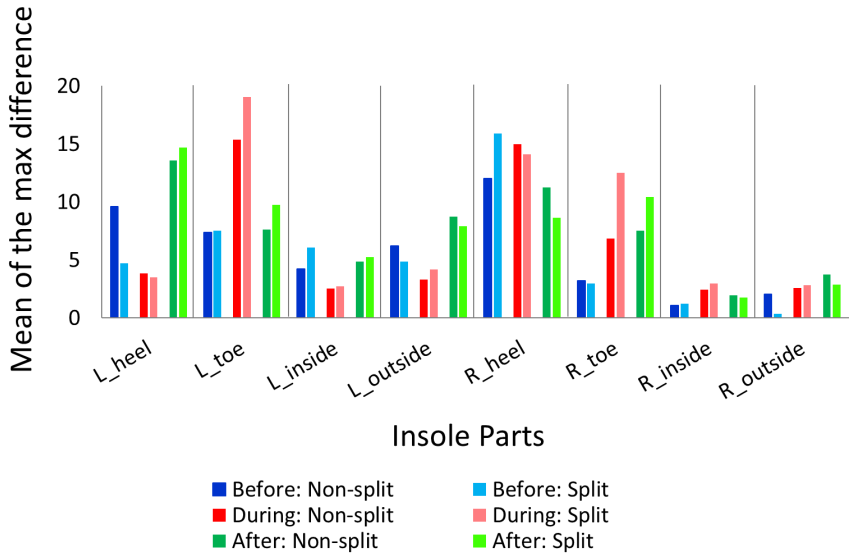
Mean peak values

- After robot removal :
  - Left heel and left outside peaks increased
  - Right heel peak decrease
    → reduced asymmetry
  - Right toe peak increased



Decline Rate

- Results shown for segmented (“split”) and nonsegmented (“non-split”) data



- Overall decay rates higher after robot removal than before use.
- Left side
  - Slight decrease at inside region (split data), increases elsewhere, pronounced at left heel.
- Right side :
  - Heel decreased, increases elsewhere, most prominently at toe.

DISCUSSION

- Segmentation excluded irregular gait (e.g., U-turns); mode of stride time used for robustness
- Threshold choice affects balance between excluding irregular data and keeping valid data
- Threshold trade-off:
  - Lower threshold: stricter exclusion, risk of omitting valid walking
  - Higher threshold: more inclusion, risk of irregular data
- Adjust settings by walking speed and balance
- Split data showed limited steps, insufficient alone → need longer + additional segments
- Irregular gait phases (e.g., turning) important for fall risk; future analyses should include them
- Segmented data are useful for detecting key changes after robot-assisted walking

CONCLUSIONS / ACKNOWLEDGMENT

Conclusions

- Using mode of stride time minimized extreme values and enabled effective segmentation
- This approach revealed gait improvement effects of a gait-assist robot in rehabilitation
- Practical utility of smart insoles depends on digital functions and design for comfort and usability in daily life
- As a single-case study, generalizability is limited
- Future work: larger sample size, further refinement of measurements, analysis methods, and insole design

Acknowledgment

- Sincere gratitude to the patient and hospital staff for their participation
- Supported by JSPS KAKENHI (Grant No. JP23K11207)

Thank you for reading