Heel-Strike Detection Algorithm For Exoskeleton Walking With Spinal Cord Injury

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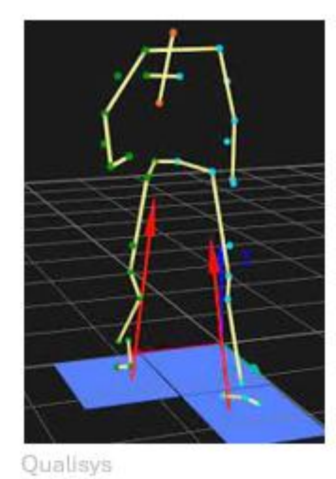
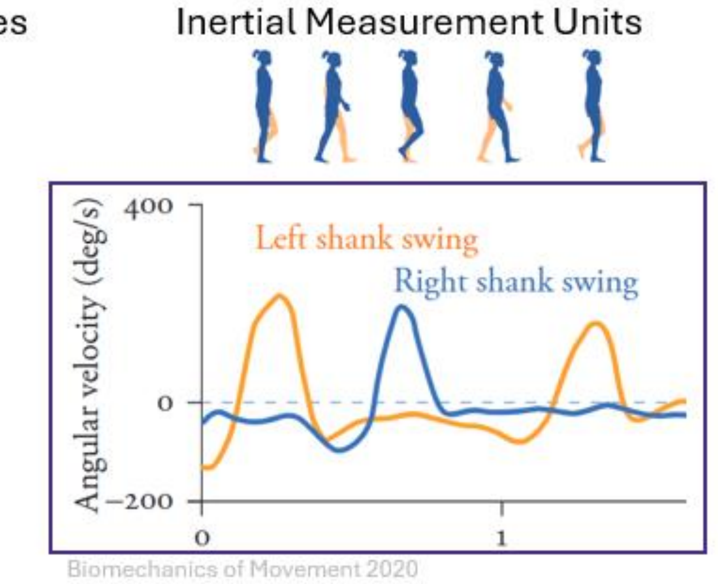
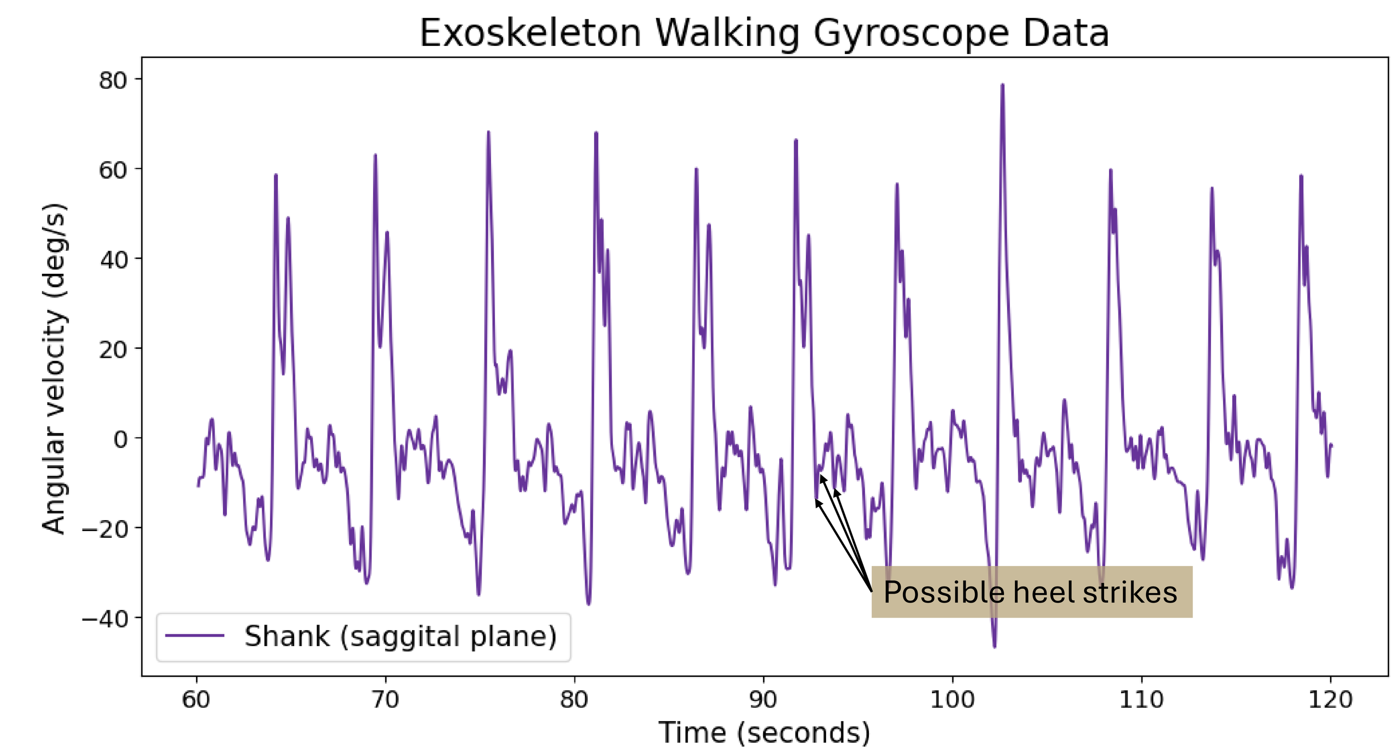
Automated heel-strike detection is important for exoskeleton walking

Gait rehabilitation after spinal cord injury





Evaluate success via stride-segmented biomechanics signals

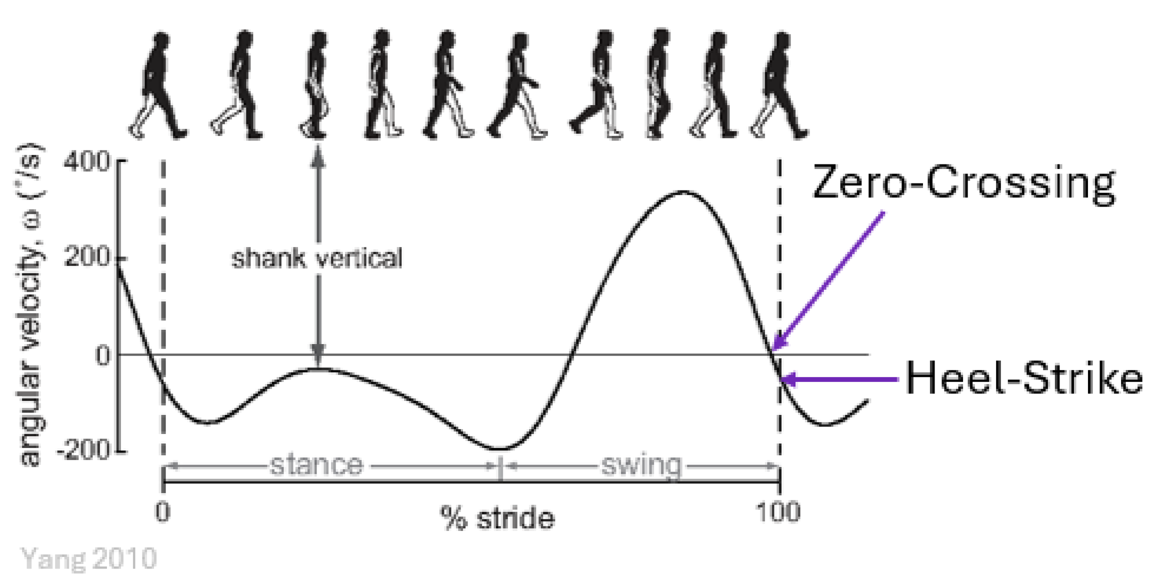


Exoskeleton walking makes stride segmentation signal "noisy"

Time-consuming, difficult to segment manually (adds bias)

Prior works [1-3]:
✓ Automated heel-strike detection
⊗ Not for exoskeleton walking with SCI

Methods for Detection



Detection Algorithm

Find mid-swing peak → Find local minimum → Identify heel-strike

adaptive threshold | after mid-swing | zero-crossing point

Equation [1]:

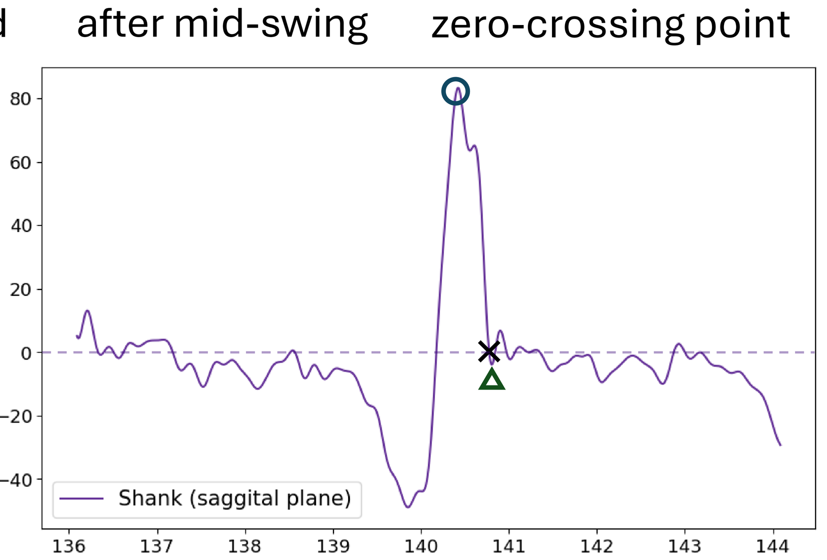
$x_1 = mean\ (data)$

$g = data > x_1$

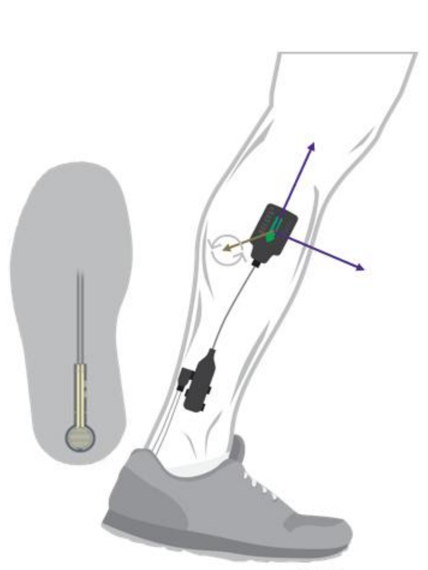
$x_2 = mean\ (g)$

$th = 0.8 * x_2$

Valid mid-swing peak must be > th

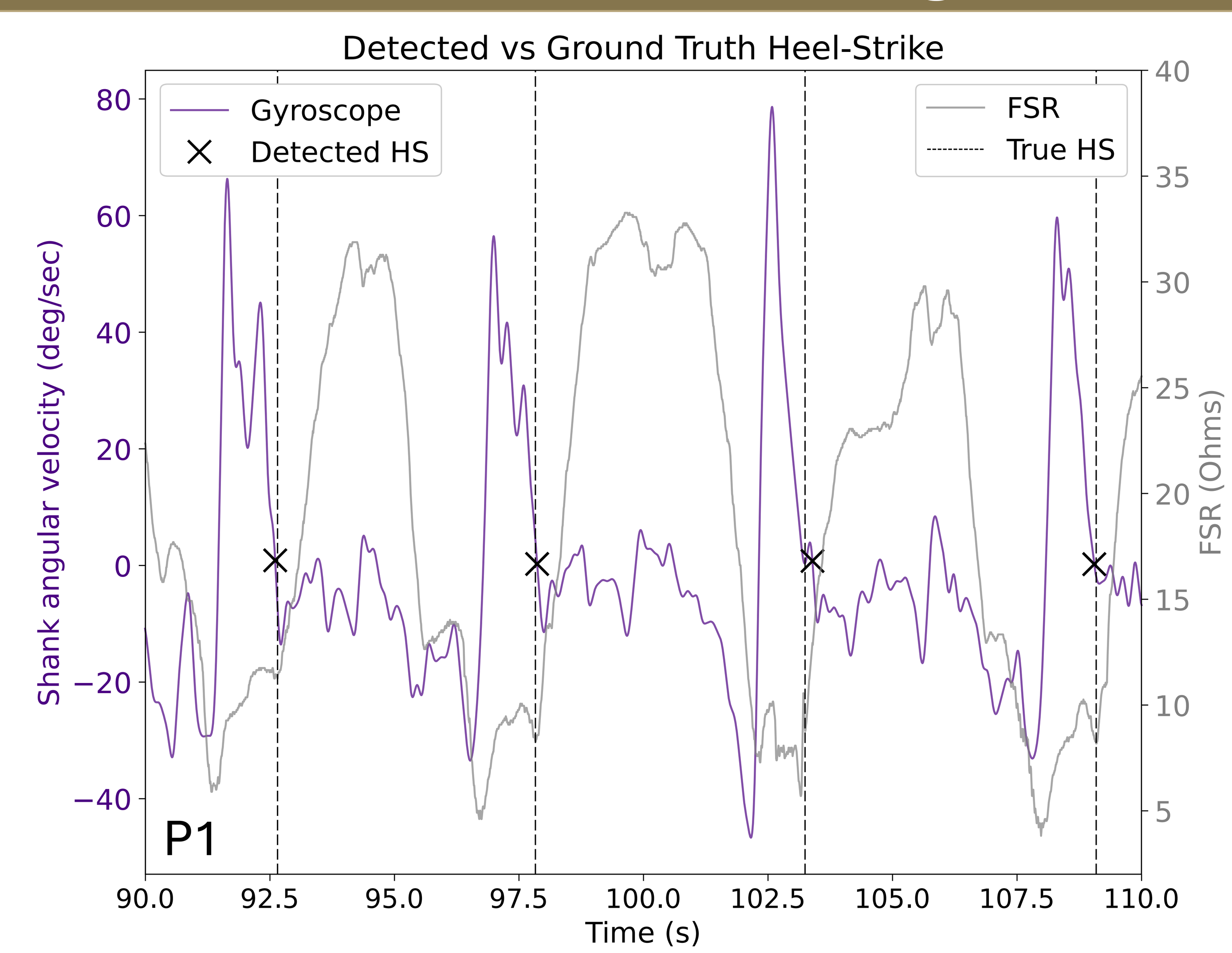


Ground-Truth Validation



- Mid-heel force-sensitive resistor data for ground truth heel-strike
- Representative participant with spinal cord injury (SCI) (male, age 49, injury level C6, AIS C)
- Ekso Bionics exoskeleton using the ProStep+ mode

Zero-Crossing Heel-Strike Detection

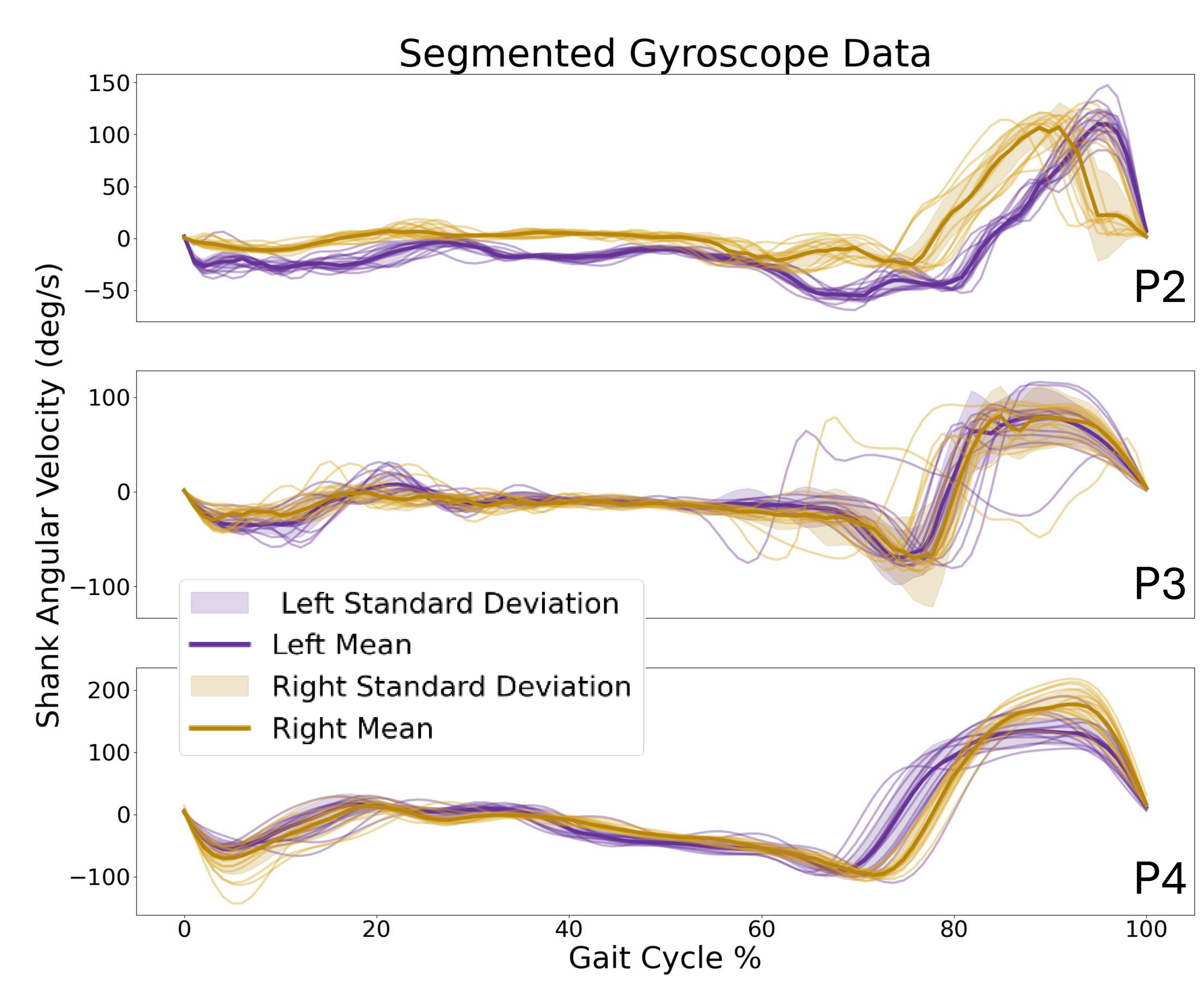


Accurate for Exoskeleton Walking

- Validation over 2 minutes of continuous walking data (n=1)
- Overall mean heel strike error 10-150ms
- Mean-squared error = 71ms for left leg; 93ms for right leg

Robust to Individual Gait Variation

- Applied algorithm to exoskeleton walking data from three different participants
- Successful consistent stride segmentation of sagittal-plane gyroscope data
- Outlier traces for P3 likely toe scuff instances



Significance

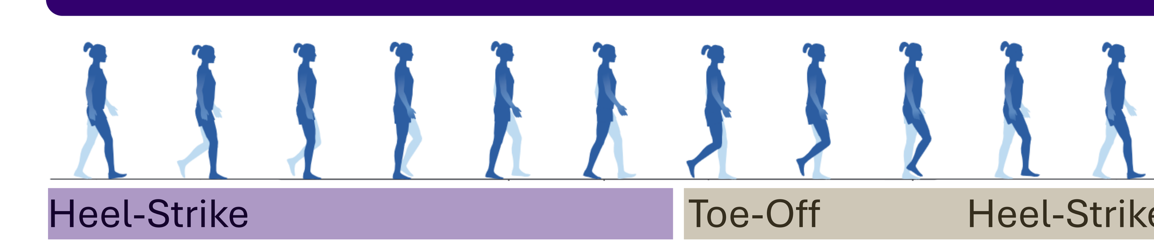
Maximum error **< 2.7%** of gait cycle

- Participant average step duration = 5.5 seconds
- Prior works report errors on the order of 10s of milliseconds, validated by force plate data [1,2]

Validated across participants with SCI

- Adults with SCI have variable gait speed and impact kinematics
- Adaptive algorithm successfully segmented stride data

Future Directions



→ Sub-segment gait cycle
→ Improve detection while quiet standing, pivoting

Acknowledgements

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References

[1] B. R. Greene *et al.*, "An adaptive gyroscope-based algorithm for temporal gait analysis," *Med. Biol. Eng. Comput.*, vol. 48, no. 12, pp. 1251–1260, Dec. 2010.
[2] Y. C. Han *et al.*, "Gait Phase Detection for Normal and Abnormal Gaits Using IMU," *IEEE Sens. J.*, vol. 19, no. 9, pp. 3439–3448, May 2019 .
[3] J. M. Jasiewicz *et al.*, "Gait event detection using linear accelerometers or angular velocity transducers in able-bodied and spinal-cord injured individuals," *Gait Posture*, vol. 24, no. 4, pp. 502–509, Dec. 2006.