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What is the Real Gait of Amputees? Using IMUs for Ecological Clinical Motion Capture

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1. Introduction

Transfemoral amputation is a life-altering event with immediate and profound consequences on daily life activities and quality of life. Gait analysis studies in transfemoral amputees (TFA) consistently report asymmetrical lower-limb movements and compensatory strategies of the pelvis and trunk compared to able-bodied individuals (Persine et al., 2022).

Navigating urban environments demands locomotor skills which are challenging to TFA people. Indeed, sidewalks, pavements and roadways are commonly inclined to ensure water drainage, imposing continuous adaptations in lower-limb, trunk and pelvis kinematics (Persine et al., 2023).

Reproducing these ecological conditions in a laboratory remains inherently challenging. Embedded motion capture using Inertial Measurement Units (IMUs) thus represents a promising and clinically relevant complement to conventional optoelectronic systems. The primary aim of this study is to evaluate the impact of ecologically relevant urban conditions on TFA gait, and to assess the potential of IMU-based measurement in this population.

2. Methods

2.1 Protocol

A cohort of 6 right leg TFA / 6 control subjects (mean age 41.7 / 28.3yrs, height 175.0 / 171.7cm, mass 80.3 / 71.5kg) were equipped with IMU sensors (Movella DOT) on both dorsal sides of the feet, both lateral sides of the thigh and the back (between both scapulae). Subjects were then asked to walk outside in a straight line over 3 roads: flat, downhill and uphill. Road inclination was 3.5% and lateral inclination was between 0 and 2%. Rest periods were given between trials.

2.2 Data Processing

IMU data was acquired at 120Hz, data from the first 25 steps (excluding initiation steps) were kept. The first step consisted in reorienting the feet IMU reference frame relative to gravity and the principal rotation axis to detect gait events (Ullrich et al., 2020). Spatiotemporal parameters were then computed: step length, stride duration, and swing and stance duration as a percentage of stride. Finally, segment kinematics were extracted from IMU quaternion values. Thigh flexion angles, back flexion/extension, lateral flexion and rotation range of motion (ROM) were computed and expressed as 100% of the stride cycle.

2.3 Statistical Analysis

Discrete (resp. Continuous) data was analyzed through a non-parametric one-way 0D (resp. 1D) ANOVA with repeated measures to assess the impact of walking condition using the SPM methodology (Pataky, 2012). Multiple analysis were dealt with using Holms (resp. Bonferroni) corrections. Data processing and statistical calculations were carried out using Matlab (R2025B).

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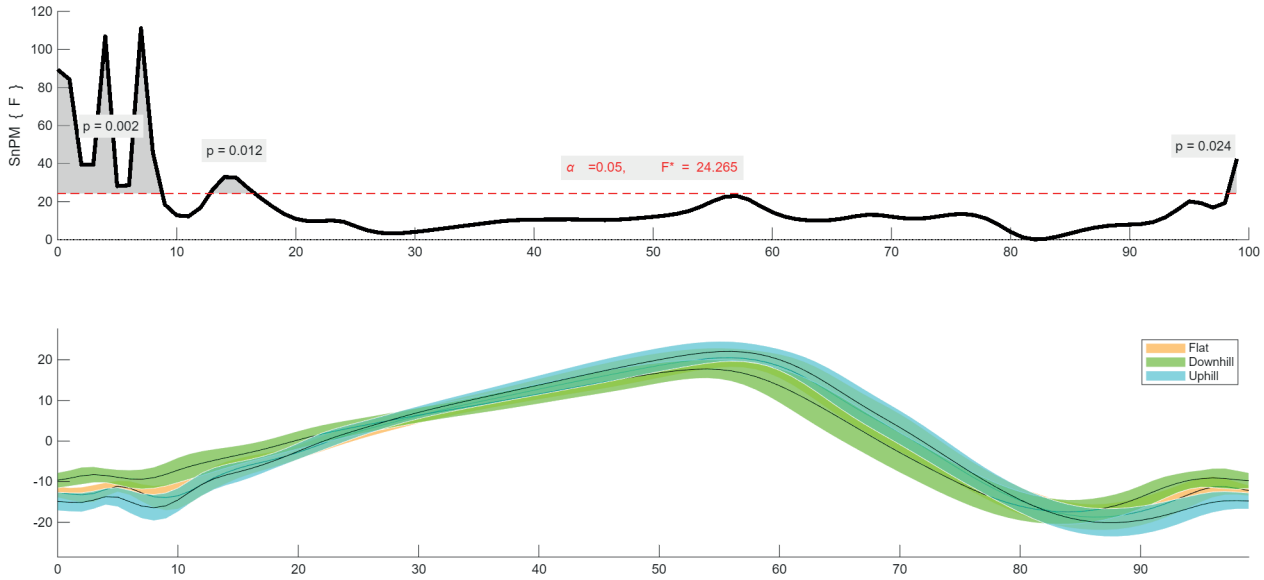

Figure 1. SPM analysis of left thigh flexion-extension within TFA subjects at three different walking condition.

3. Results and discussion

Discrete results from spatiotemporal data and kinematic ROM can be found in Table 1. After corrections, two parameters significantly discriminated between walking conditions for TFA subjects only.

Table 1. Results of discrete data analysis (1st row TFA, 2nd row Control). Significant results are in bold.

Parameter	Flat	Downhill	Uphill	p-value
R stride length (m)	1.3+/-0.1 1.6+/-0.1	1.2+/-0.1 1.6+/-0.1	1.2+/-0.2 1.6+/-0.1	0.06 0.34
L stride length (m)	1.3+/-0.1 1.5+/-0.2	1.2+/-0.1 1.6+/-0.1	1.3+/-0.1 1.6+/-0.1	0.01 0.35
R stride duration (s)	1.3+/-0.2 1.0+/-0.1	1.3+/-0.2 1.0+/-0.0	1.4+/-0.2 1.0+/-0.0	0.64 0.65
L stride duration (s)	1.3+/-0.2 1.0+/-0.1	1.3+/-0.2 1.0+/-0.0	1.4+/-0.2 1.0+/-0.0	0.67 0.68
R stance (%)	57.8+/-2.2 56.5+/-2.3	58.2+/-3.1 56.4+/-2.2	57.7+/-1.8 56.2+/-2.1	0.72 0.88
L stance (%)	59.6+/-3.1 55.8+/-2.4	60.3+/-3.3 55.1+/-2.2	59.5+/-2.5 55.6+/-2.0	0.63 0.17
Stride asym. (s)	0.0+/-0.0 -0.0+/-0.0	-0.0+/-0.0 -0.0+/-0.0	-0.0+/-0.1 -0.0+/-0.0	0.59 0.75
Stance asym. (%)	-1.9+/-4.4 0.8+/-1.9	-1.8+/-5.3 1.4+/-1.7	-1.9+/-3.3 0.8+/-1.7	0.99 0.61
ROM R thigh (°)	**47.2+/-8.2** 41.9+/-4.0	**42.4+/-6.9** 39.2+/-3.9	**47.9+/-7.2** 41.7+/-3.9	**0.01** 0.22
ROM L thigh (°)	**40.2+/-4.9** 40.3+/-4.7	**36.3+/-4.4** 40.4+/-3.6	**42.9+/-5.0** 43.3+/-4.6	**0.00** 0.01
ROM flex-lat back (°)	7.8+/-2.1 5.7+/-1.7	7.3+/-1.5 5.1+/-1.6	9.1+/-2.2 6.0+/-1.4	0.06 0.08
ROM flex-ext back (°)	8.0+/-2.4 5.5+/-1.5	6.6+/-1.9 6.9+/-1.6	9.4+/-2.6 5.9+/-1.8	0.04 0.06

Results for continuous data were coherent with discrete: both thigh flexion-extension angles produced significant results at various instants of the gait cycle (cf. Fig. 1), whereas no continuous parameter was significantly different for control subjects. Full statistical analysis can be found in supplementary material here (https://uphf.hal.science/hal-05647822).

The present findings suggest that TFA are more affected than control subjects by inclined surfaces, increasing compensatory demands on the pelvis and trunk. These results are clinically meaningful, as inclined surfaces are ubiquitous in urban environments yet rarely addressed during rehabilitation.

Our finding that TFA gait is affected by inclined surfaces is consistent with previous laboratory-based studies like (Vrieling et al. 2008) and (Rodrigues et al. 2019). However, direct comparison with these studies warrants caution due to methodological differences inherent to laboratory settings. Vrieling et al. used a 2-meter ramp at 5% gradient, a distance likely insufficient for gait to reach a steady state, potentially introducing transient adaptation effects into their measurements. Rodrigues et al. tested inclinations of 8%, which substantially exceeds the slopes encountered in the present study. These methodological discrepancies highlight the need for larger outdoor datasets to enable more robust comparisons across studies and to better characterize the impact of inclined surfaces on amputee gait under real-world conditions.

The small cohort size limits statistical power and prevents definitive conclusions; larger studies are needed to confirm these trends. Regarding IMU precision, current fusion algorithms were largely validated for level walking, and their accuracy may be reduced on lateral slopes due to sensor drift. Advances in adaptive calibration and machine-learning-based signal processing are expected to improve the sensitivity of IMU-derived parameters, making embedded motion capture a more viable tool for ecological gait assessment in TFA.

4. Conclusions

This study supports the use of IMU-based gait assessment in ecological conditions, offering two complementary benefits: enriching clinicians' understanding of patients' real-world locomotor challenges, and improving patient engagement by shifting evaluation toward meaningful everyday environments. As IMU technology matures, embedded motion capture holds promise as a standard tool for functional gait assessment in TFA rehabilitation.

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Conflict of Interest Statement

The authors declare no conflict of interest.

Contributor Roles

MB: Conceptualization, Methodology, Software, Visualization, Writing original draft; SP: Conceptualization, Methodology Funding acquisition, Resources, Writing – review & editing, Data curation.

References

Pataky, T. C. (2012). One-dimensional statistical parametric mapping in Python. *Computer Methods in Biomechanics and Biomedical Engineering, 15*(3), 295–301. https://doi.org/10.1080/10255842.2010.527837

Persine, S., Leteneur, S., Gillet, C., Bassement, J., Charlaté, F., & Simoneau-Buessinger, E. (2022). Walking abilities improvements are associated with pelvis and trunk kinematic adaptations in transfemoral amputees after rehabilitation. *Clinical Biomechanics, 94*, 105619. https://doi.org/10.1016/j.clinbiomech.2022.105619

Persine, S., Simoneau-Buessinger, E., Charlaté, F., Bassement, J., Gillet, C., Découfour, N., & Leteneur, S. (2023). Transfemoral amputees adapt their gait during cross-slope walking with specific upper-lower limb coordination. *Gait & Posture, 105*, 171–176. https://doi.org/10.1016/j.gaitpost.2023.08.001

Rodrigues, F. B., Andrade, A. O., & Vieira, M. F. (2019). Effects of inclined surfaces on gait variability and stability in unilateral lower limb amputees. *Med Biol Eng Comput, 57*(11), 2337–2346. https://doi.org/10.1007/s11517-019-02042-6

Ullrich, M., Küderle, A., Hannink, J., Din, S. D., Gaßner, H., Marxreiter, F., Klucken, J., Eskofier, B. M., & Kluge, F. (2020). Detection of gait from continuous inertial sensor data using harmonic frequencies. *IEEE Journal of Biomedical and Health Informatics, 24*(7), 1869–1878. https://doi.org/10.1109/JBHI.2020.2975361

Vrieling, A. H., van Keeken, H. G., Schoppen, T., Otten, E., Halbertsma, J. P. K., Hof, A. L., & Postema, K. (2008). Uphill and downhill walking in unilateral lower limb amputees. *Gait & Posture, 28*(2), 235–242. https://doi.org/10.1016/j.gaitpost.2007.12.006