2024

Longitudinal Monitoring of Gait Parameters for Lower Limb Prosthetic Users with Physical Therapy Using Video-Based Gait Analysis

Alisha Agarwal, BS
Thomas Jefferson University, alisha.agarwal@students.jefferson.edu

Anthony Cimorelli, CPO
Shirley Ryan AbilityLab

R. James Cotton, MD, PhD
Shirley Ryan AbilityLab; Northwestern University

Recommended Citation
Agarwal, BS, Alisha; Cimorelli, CPO, Anthony; and Cotton, MD, PhD, R. James, "Longitudinal Monitoring of Gait Parameters for Lower Limb Prosthetic Users with Physical Therapy Using Video-Based Gait Analysis" (2024). *Alpha Omega Alpha Research Symposium Posters*. 5.
https://jdc.jefferson.edu/aoa_research_symposium_posters/5

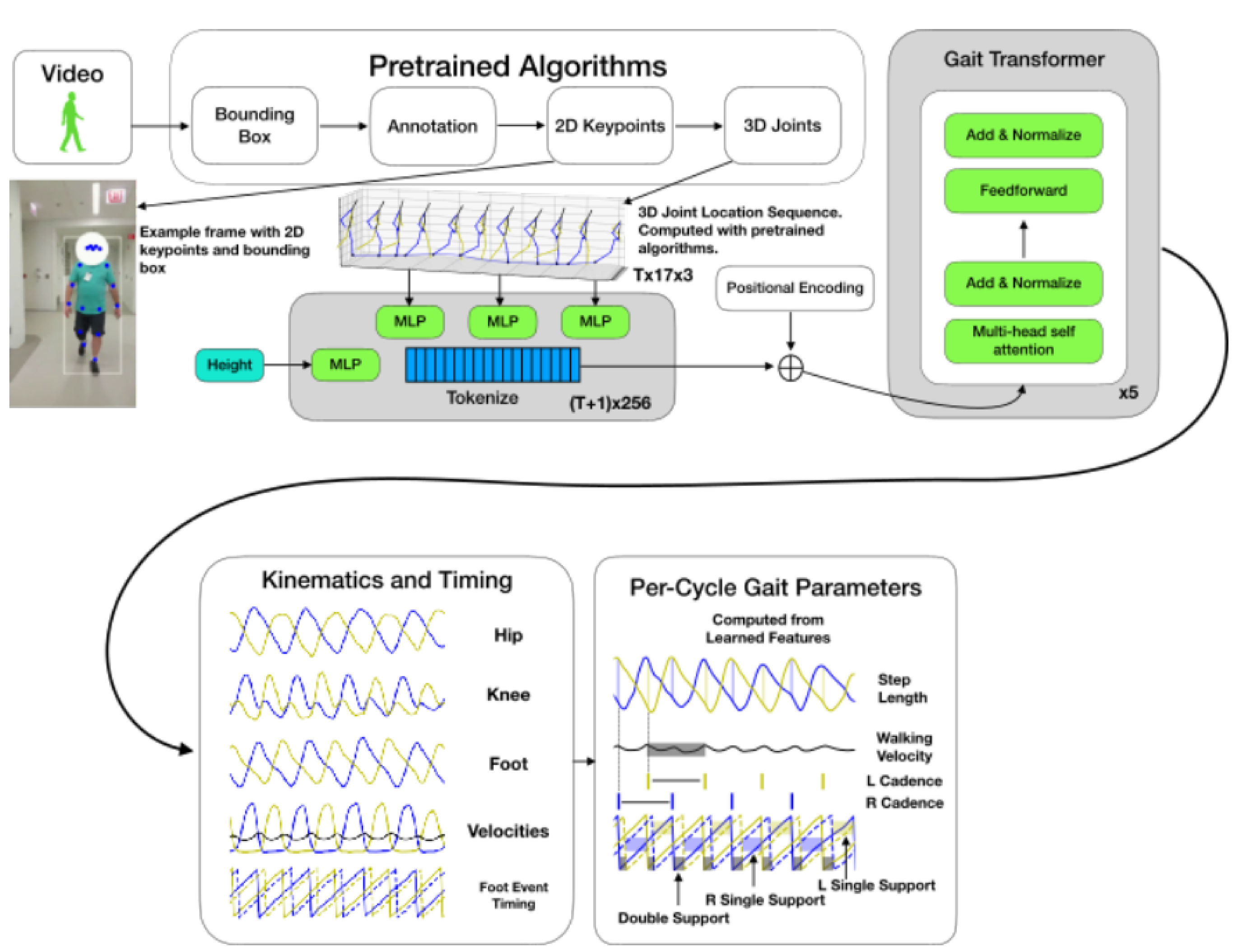
Longitudinal Monitoring of Gait Parameters for Lower Limb Prosthetic Users with Physical Therapy using Video-Based Gait Analysis

Alisha Agarwal BS[1], Anthony Cimorelli, MSPO, CPO[2]; R. James Cotton, MD, PhD[2,3]
[1]Sidney Kimmel Medical College, Philadelphia, PA; [2]Shirley Ryan AbilityLab, Chicago, IL; [3]Department of Physical Medicine and Rehabilitation, Northwestern University, Chicago, IL

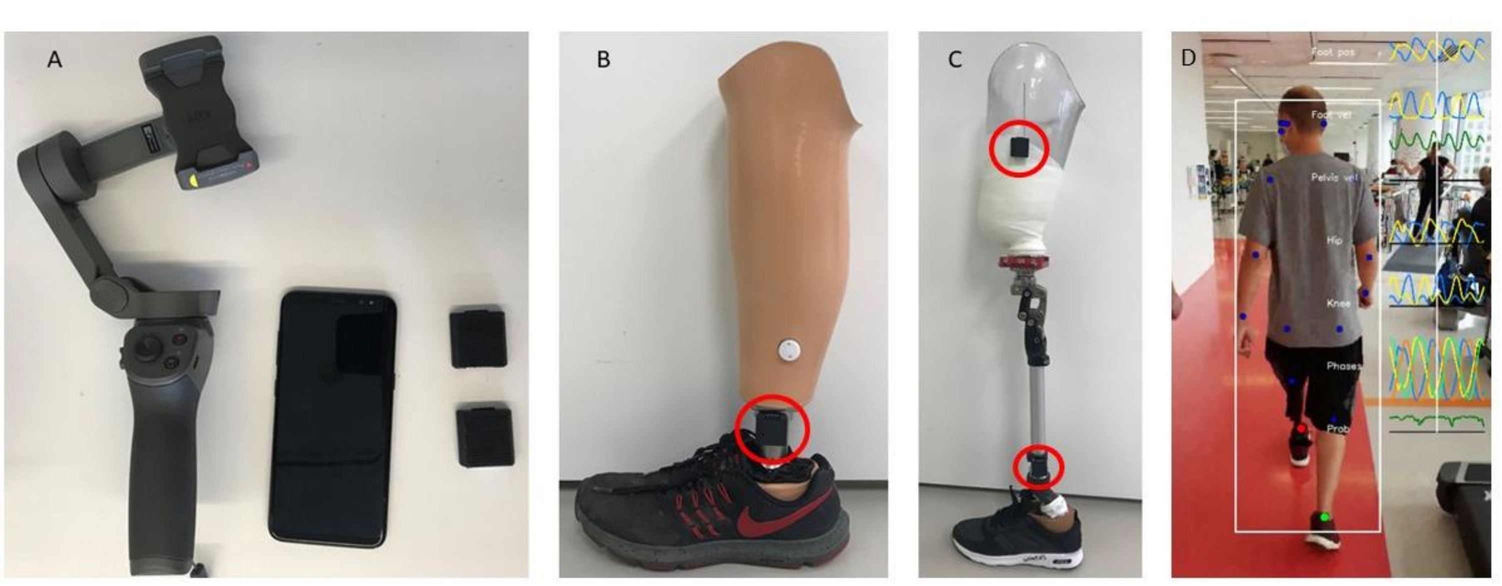
Introduction

Gait training in physical therapy is a common standard of practice for new lower limb prosthetic users. Progress is typically assessed through functional outcome measures such as the 10-meter or 6-minute walk tests[1]. While these tests measure walking speed and endurance, they fall short of capturing gait quality or quantifying gait parameters which literature shows to be of therapeutic value[2,3]. Routine access to quantitative gait assessment could provide clinicians with benchmarks to optimize treatment interventions. Traditional gait analysis systems require specialized equipment making them very resource-intensive and inconvenient to operate. Using human pose estimation techniques, we have developed and trained a custom gait analysis system that allows us to measure spatiotemporal gait parameters from video[4,5]. Lower limb prosthetic users were recorded while ambulating during routine physical therapy appointments. Manual annotation of these videos was used to categorize system performance. The goal of the study was to demonstrate if longitudinal tracking of various gait parameters such as cadence and velocity across numerous subjects showed improvements that reflected coinciding functional outcome measures.

Overview of Custom Gait Analysis Pipeline



Overview of Gait Analysis System



A: Android cell phone, wearable sensors and gimbal. B/C: Sensors placed on transtibial and transfemoral prostheses. D: Example output from system.

Materials & Methods

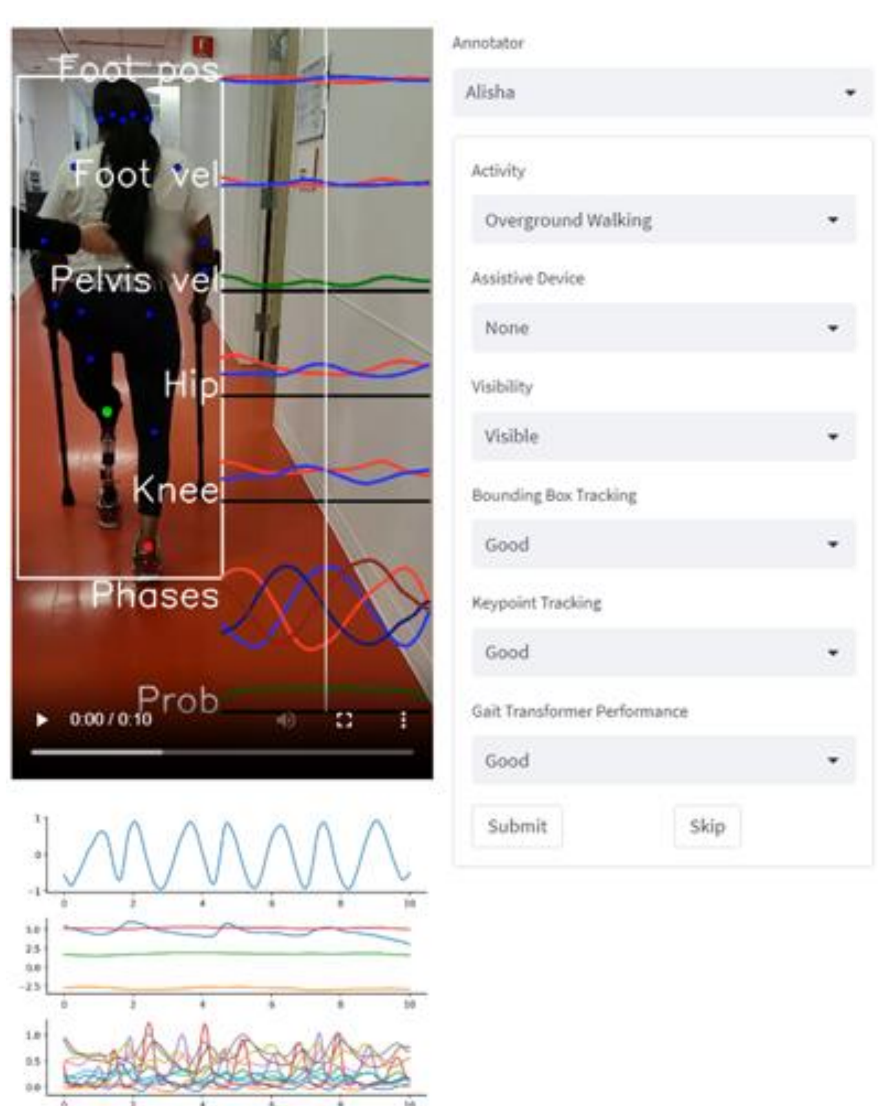
Total Subjects	N = 25 Individual with LLA
Gender	16 male, 5 Female
Age	Average: 55.7, Range: 22-77
K-Level	17 K3, 3K2, 1 undefined
Level of Amputation	11 TT, 2 B-TT, 6 TF, 1 B-TF, 1 HD
Etiology of Amputation	5 Trauma, 6 Infection, 6 Vascular, 4 Sarcoma
Prosthetic Componentry	Knee, foot, interface varied

Procedures: Data were collected during normal physical therapy visits at Shirley Ryan AbilityLab. Custom wearable sensors were placed on the shank and thigh of the prosthetic limb. Video and sensor data were obtained through a custom app on an Android cell phone as ambulation occurred naturally throughout clinical visits.

Data Processing: Processing of the videos was performed using our custom gait analysis pipeline[4,5] to measure cadence, velocity, and other spatiotemporal parameters.

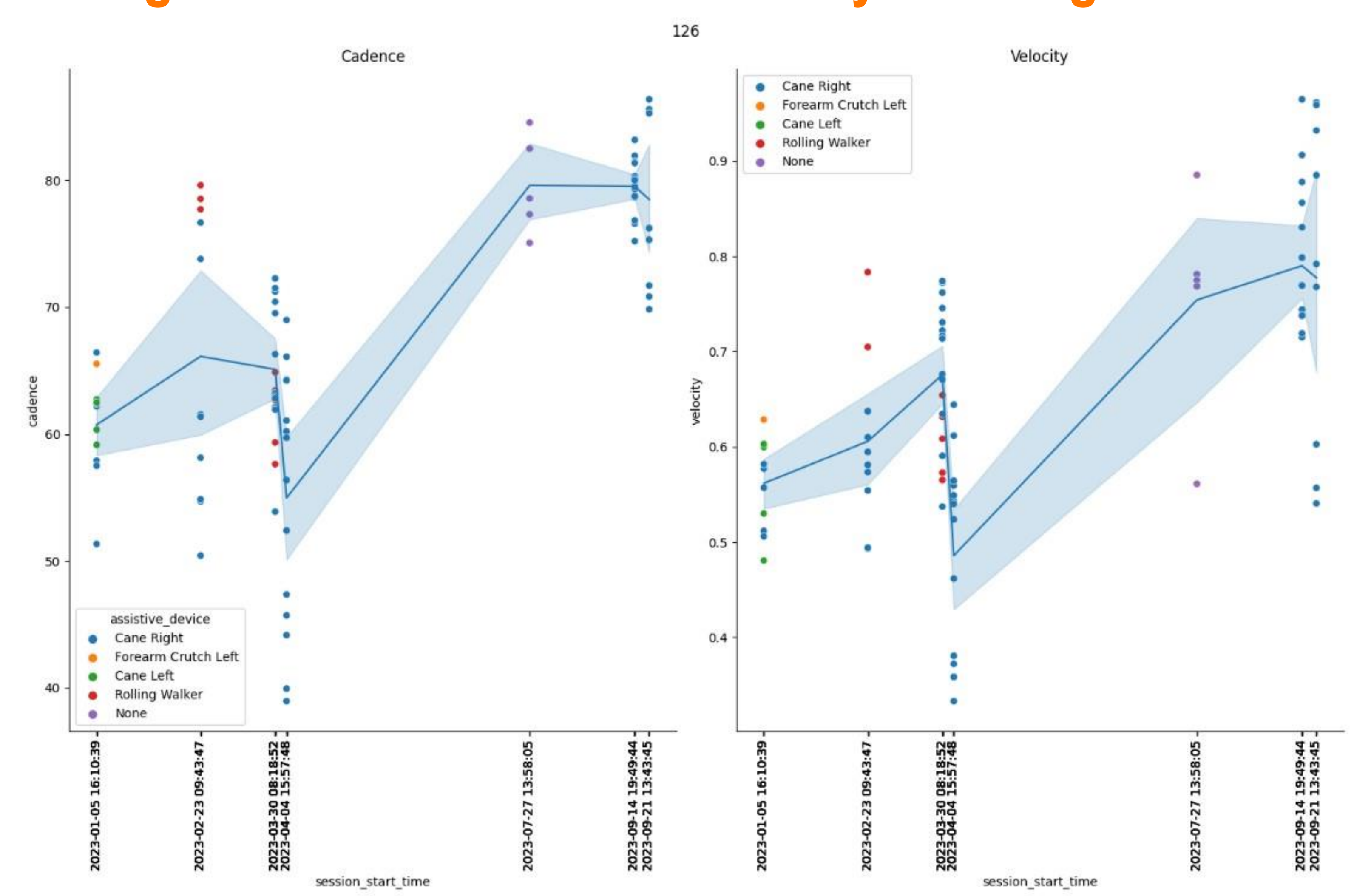
Manual Annotation: Recorded videos were divided into ten second clips and annotated using a custom annotation GUI. Performance and labelling of the following categories were marked: activity performed, assistive device, visibility, bounding box tracking, keypoint tracking and gait transformer outputs.

Manual Annotation GUI Interface



Longitudinal Tracking: The following filters were used to determine which videos to utilize for longitudinal tracking: Activity Being Performed = "Overground Walking", Visibility = "Visible", Bounding Box Tracking = "Good", Keypoint Tracking ="Good", and Gait performance ="Good". These filters were used to standardize assessment of videos and avoid confounding effects of transformer performance on spatiotemporal calculations.

Longitudinal Cadence and Velocity Tracking



Cadence and Velocity outputs for Subject 126 stratified by assistive device. The results correlated closely with the functional outcome measures obtained in therapy. For example, the 10-meter walk test on 2/23 was measured to be 0.55m/s with a cane. Our gait transformer outputted an average of 0.57m/s.

Conclusion

Manual annotations of video segments helped elucidate the circumstances in which the gait transformer performed better. Namely, the keypoint tracking and gait transformer performance were consistently better on transtibial prosthetic users compared to higher level prosthetic users. Performance was also better when the individual was wearing clothing covering much of the prosthesis, likely due to improved similarities this provided to an able-bodied leg. When the gait transformer performance was good, the spatiotemporal outputs mapped well with their counterpart functional outcome measures when analyzing longitudinal improvements in gait. Future work will explore ways to further automate the system, improve tracking on higher level prosthetic users and determine how the system can be used to aide in clinical decision making.

The ability to easily measure quantitative gait parameters in clinical settings could have far reaching implications. For example, it would provide clinicians with specific benchmarks by which to optimize therapeutic goals and interventions, or aid prosthetists with dynamic alignment. Also, it could provide additional information to insurance companies that an individual is still making improvements in therapy when other measures have plateaued.

Acknowledgments

This work was supported by the Research Accelerator Program of the Shirley Ryan AbilityLab and NIDILRR grant number 90REGE0003.

References

1. Jennifer L. Moore, Kirsten Potter, Kathleen Blankshain, Sandra L. Kaplan, Linda C. O'Dwyer, and Jane E. Sullivan. A Core Set of Outcome Measures for Adults With Neurologic Conditions Undergoing Rehabilitation: A CLINICAL PRACTICE GUIDELINE. Journal of Neurologic Physical Therapy, 42(3):174–220, July 2018. ISSN 1557-0576. doi: 10.1097/NPT.0000000000000229
2. Feng Yang and Yi-Chung Pai. Can stability really predict an impending slip-related fall among older adults? Journal of Biomechanics, 47(16):3876–3881, December 2014. ISSN 1873-2380. doi: 10. 1016/j.jbiomech.2014.10.006.
3. Chang, A., Hayes, K., Dunlop, D., Hurwitz, D., Song, J., Cahue, S., Genge, R., & Sharma, L. (2004). Thrust during ambulation and the progression of knee osteoarthritis. Arthritis & Rheumatism, 50(12), 3897–3903. https://doi.org/10.1002/art.20657
4. Cotton R J. PosePipe: Open-Source Human Pose Estimation Pipeline for Clinical Research. Preprint: https://arxiv.org/abs/2203.08792
5. Cotton R J, et al. Transforming Gait: Video-Based Spatiotemporal Gait Analysis. *IEEE EMBC 2022 Conference Proceedings*

Contact Information:
Alisha Agarwal: aya138@students.Jefferson.edu | Anthony Cimorelli: acimorelli@sralab.org | R. James Cotton: rcotton@sralab.org

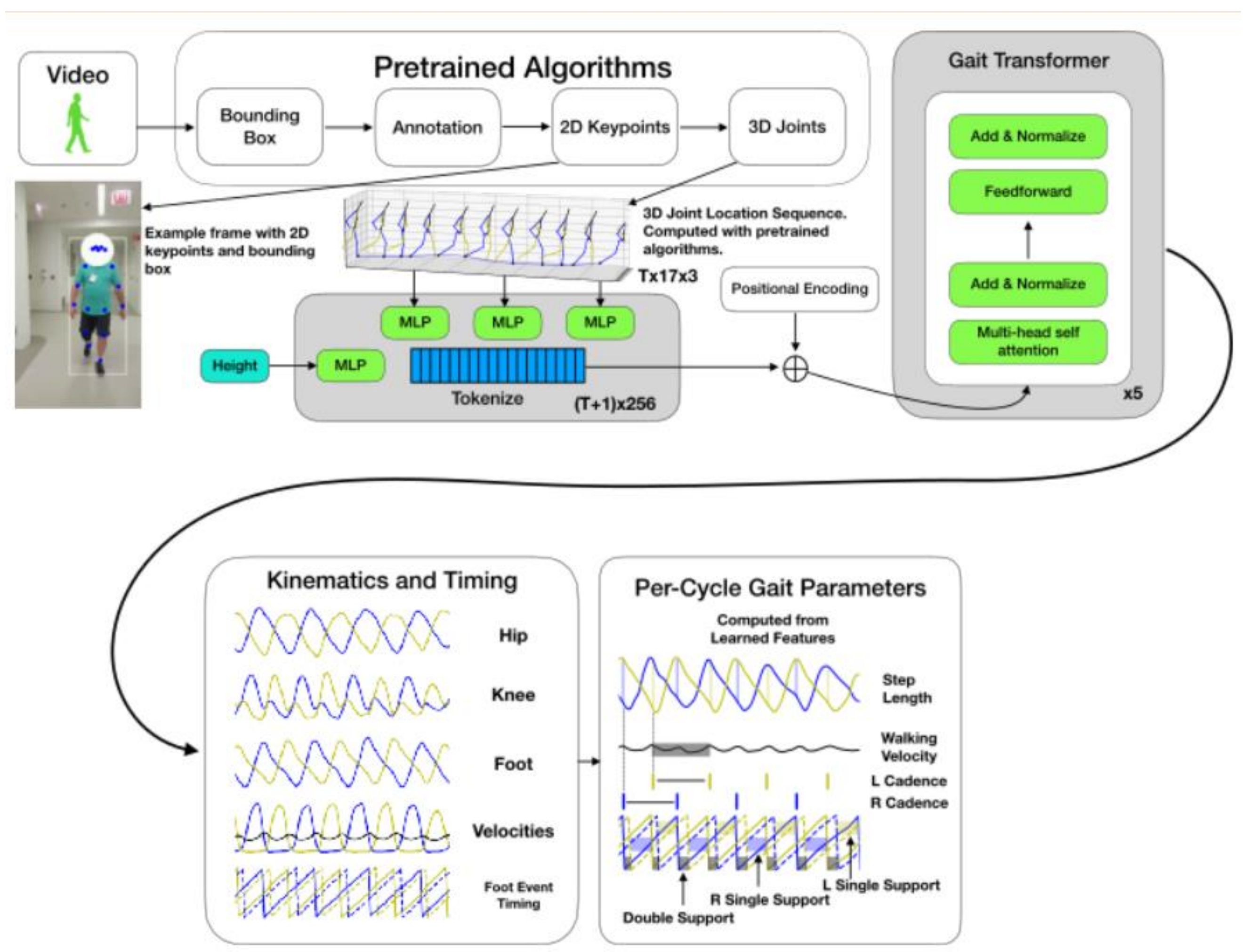
Longitudinal Monitoring of Gait Parameters for New Lower Limb Amputees with Physical Therapy using Video-Based Gait Analysis

Alisha Agarwal BS[1], Anthony Cimorelli, MSPO, CO[2]; R. James Cotton, MD, PhD[2,3]
[1]Sidney Kimmel Medical College, Philadelphia, PA; [2]Shirley Ryan AbilityLab, Chicago, IL; [3]Department of Physical Medicine and Rehabilitation, Northwestern University, Chicago, IL

Introduction

Gait training in physical therapy is a common standard of practice for new lower limb prosthetic users. While these tests can measure walking speed and endurance, they fall short of capturing gait quality or quantifying gait parameters which literature shows to be of therapeutic value [1,2]. Traditional gait analysis requires specialized equipment making it very resource-intensive and inconvenient for the patient. Using human pose estimation techniques, we have developed and trained a custom gait analysis system that allows us to measure spatiotemporal gait parameters from video[3,4]. Lower limb prosthetic users who were undergoing physical therapy at SRAL were recorded during their regularly therapy sessions. Manual annotation of activity, assistive device, and algorithm performance were completed. The goal of the study was to demonstrate if longitudinal tracking of various gait parameters such as cadence and velocity across numerous subjects showed improvements that reflected coinciding functional outcome measures commonly used in therapy such as the 10 meter walk test[5].

Overview of Custom Gait Analysis Pipeline



Materials & Methods

Total Subjects	N = 25 Individual with LLA
Gender	16 male, 5 Female
Age	Average: 55.7, Range: 22-77
K-Level	17 K3, 3K2, 1 undefined
Level of Amputation	11 TT, 2 B-TT, 6 TF, 1 B-TF, 1 HD
Etiology of Amputation	5 Trauma, 6 Infection, 6 Vascular, 4 Sarcoma
Time Since Amputation	
Prosthetic Componentry	Knee, foot, interface varied

Procedures: Data were collected during normal physical therapy visits at Shirley Ryan AbilityLab. Custom wearable sensors were placed on the shank and thigh of the prosthetic limb. Video and sensor data were obtained through a custom app on an Android cell phone as mobility activities occurred naturally throughout clinical visits.

Data Processing: Processing of the videos was performed using our custom gait analysis pipeline[6,7]. Gait transformer cadence was compared to that measured using the wearable sensors. Gait transformer velocity was compared to that calculated from video of the participant crossing between 2 marks separated by 10m (Annotated Velocity).

Manual Annotation: Recorded videos were divided into ten second clips and annotated using a custom annotation GUI. Performance and labelling of several categories such as activity performed, assistive device, and algorithm accuracy were marked.

Longitudinal Tracking: Videos where the activity being performed was labelling "Overground Walking" , visibility labelled as "Visible", and Gait performance labelled "Good" were utilized for longitudinal tracking of cadence and velocity across therapy sessions.

Results

Your text would go here. List your information on these lines. Your text would go here. List your information on these lines.

Figure 1

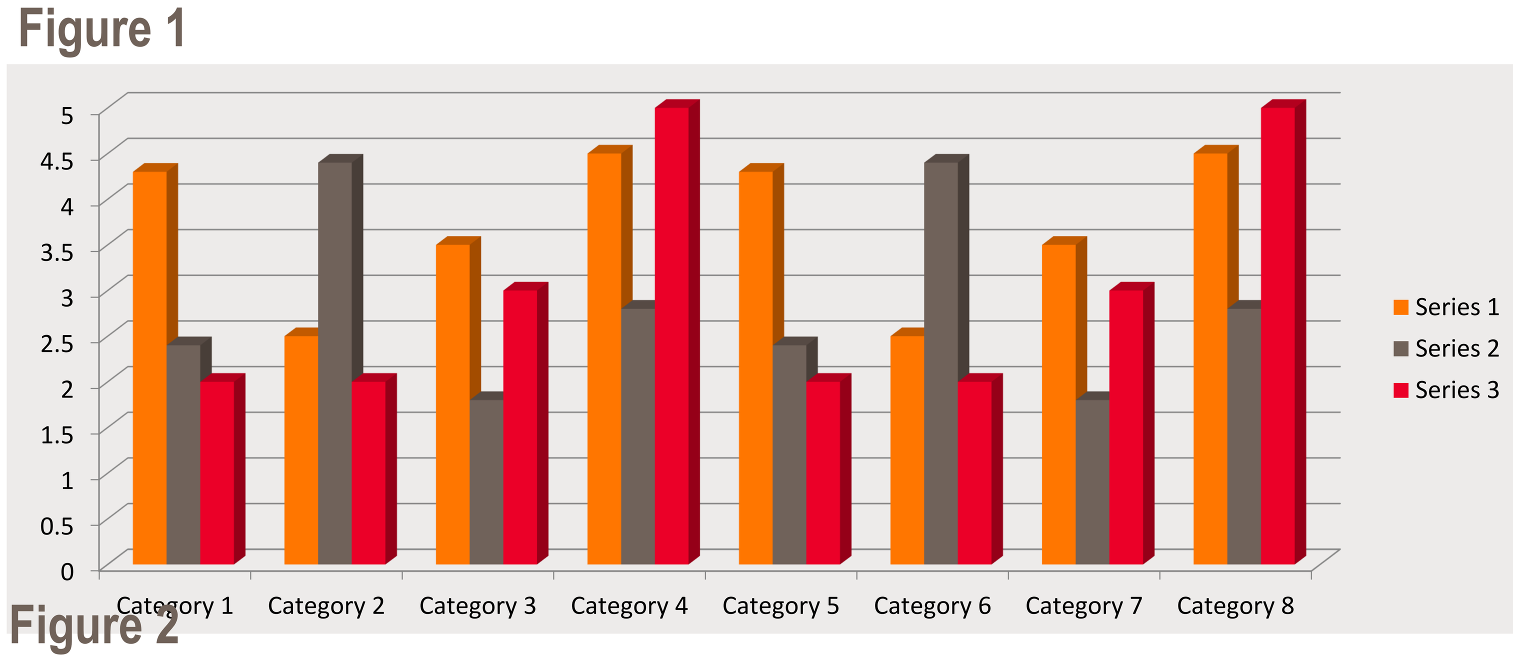
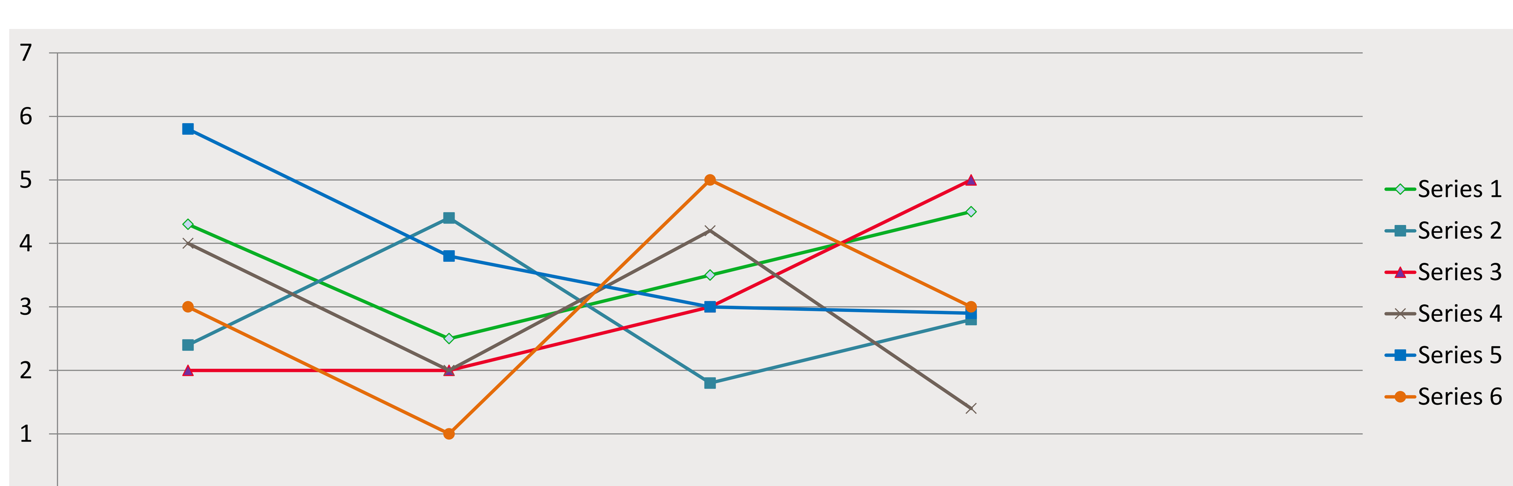


Figure 2



Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines.

- Your text would go here. List your information on these lines.
- Your text would go here.

List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines.

- Your text would go here. List your information on these lines.
- Your text would go here.
- List your information on these lines.

Conclusion

Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines.

Limitations

Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines.

- Your text would go here. List your information on these lines.
- Your text would go here.
- List your information on these lines.

Acknowledgments

Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines. Your text would go here. List your information on these lines.

References

1. Feng Yang and Yi-Chung Pai. Can stability really predict an impending slip-related fall among older adults? Journal of Biomechanics, 47(16):3876–3881, December 2014. ISSN 1873-2380. doi: 10. 1016/j.jbiomech.2014.10.006.
2. Chang, A., Hayes, K., Dunlop, D., Hurwitz, D., Song, J., Cahue, S., Genge, R., & Sharma, L. (2004). Thrust during ambulation and the progression of knee osteoarthritis. Arthritis & Rheumatism, 50(12), 3897–3903. https://doi.org/10.1002/art.20657
3. Cotton R J. PosePipe: Open-Source Human Pose Estimation Pipeline for Clinical Research. Preprint: https://arxiv.org/abs/2203.08792
4. Cotton R J, et al. Transforming Gait: Video-Based Spatiotemporal Gait Analysis. *IEEE EMBC 2022 Conference Proceedings*
5. Jennifer L. Moore, Kirsten Potter, Kathleen Blankshain, Sandra L. Kaplan, Linda C. O'Dwyer, and Jane E. Sullivan. A Core Set of Outcome Measures for Adults With Neurologic Conditions Undergoing Rehabilitation: A CLINICAL PRACTICE GUIDELINE. Journal of Neurologic Physical Therapy, 42(3):174–220, July 2018. ISSN 1557-0576. doi: 10.1097/NPT.0000000000000229

Contact Information:
Alisha Agarwal: aya138@students.Jefferson.edu | Anthony Cimorelli: acimorelli@sralab.org | R. James Cotton: rcotton@sralab.org