SIMMA: A Single-Camera Markerless Motion Capture System for Gait Analysis

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INTRODUCTION: Accurate gait analysis plays a pivotal role in diagnosing musculoskeletal and neurological disorders, tracking disease progression, and designing individualized rehabilitation programs that optimize functional recovery. Conventional gold-standard marker-based motion capture (MoCap) systems, widely adopted in biomechanics research, provide highly precise three-dimensional kinematic data but remain restricted to specialized laboratories due to their high costs, complex calibration procedures, and the need for trained personnel to operate them [1,2]. These limitations constrain their clinical utility and accessibility, particularly in outpatient or resource-limited settings. In recent years, markerless motion capture systems have emerged as a promising alternative, offering simplified setups and improved patient comfort. However, despite advances in computer vision and machine learning, most existing solutions require multi-camera arrays, extensive spatial calibration, or demonstrate reduced accuracy when compared with marker-based methods, especially for subtle joint kinematics [3-5]. Moreover, reliance on specialized hardware or controlled environmental conditions further hinders their translation into routine clinical practice. To address these challenges, this study introduces and validates **SIMMA (Single-camera Markerless Motion Capture)**, a novel approach designed to provide accessible, robust, and clinically viable three-dimensional gait analysis from a single video source. By eliminating the need for markers, multi-camera configurations, or high-end motion analysis laboratories, SIMMA has the potential to bridge the gap between research-grade motion analysis and practical clinical application.

METHODS: SIMMA's temporal gait parameters were validated using the GPJATK dataset, comprising 31 participants (16: Male, 15: Female). Sagittal view videos were processed and compared against gold-standard Vicon motion capture data. Participant data were collected using four synchronized digital video cameras (Basler Pilot piA1900-32gc, resolution: 960×540 pixels, frame rate: 25 fps) and a Vicon system (sampling rate: 100 Hz). Only recordings from sessions 1 and 3 were used to validate sagittal gait parameters. SIMMA's machine learning pipeline computed key temporal gait parameters (cadence, stride time, step time, stance time, and swing time) from RGB videos. Validity was assessed by comparing these outputs to gold-standard data using Intraclass Correlation Coefficients (ICC) to measure agreement.

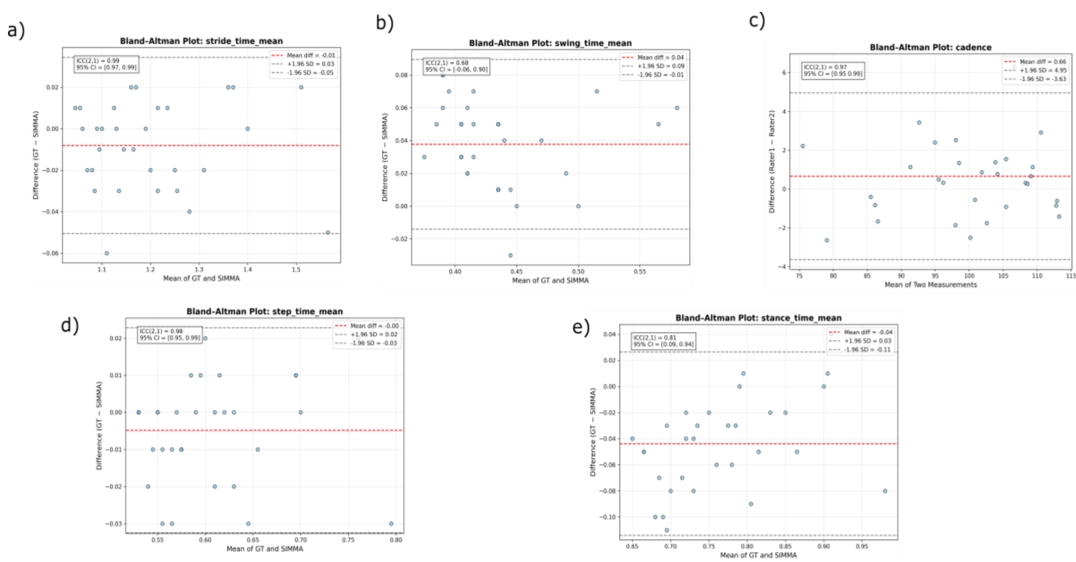

Figure 1-. Bland–Altman plots comparing SIMMA against the gold-standard motion capture system for temporal gait parameters (a) Stride time, (b) Swing time, (c) Cadence, (d) Step time, and (e) Stance time. Each plot shows the mean of the two measurements on the x-axis and their difference (GT − SIMMA) on the y-axis. The red dashed line indicates the mean difference (bias), and the gray dashed lines represent the 95% limits of agreement (±1.96 SD).

RESULTS: SIMMA demonstrated excellent agreement with the gold-standard system for key temporal gait metrics. The analysis revealed near-perfect agreement for stride time (ICC = 0.985), step time (ICC = 0.976), and cadence (ICC = 0.975). Strong agreement was observed for stance time (ICC = 0.808), and moderate agreement was found for swing time (ICC = 0.685). These results confirm robust performance across the primary components of the gait cycle for a sample size of 31 participants. Bland–Altman plots (Fig. 1a–e) illustrate the agreement between SIMMA and the gold-standard system across stride (a), swing (b), cadence (c), step (d), and stance (e) parameters.

DISCUSSION: These findings establish SIMMA as a valid tool for measuring critical temporal gait parameters, with high ICC values indicating accuracy comparable to laboratory-based systems. SIMMA employs a sophisticated biomechanical skeletal model to enhance the precision of spatiotemporal and phase-specific gait parameters, incorporating a standardized virtual marker set for seamless integration with musculoskeletal modeling platforms such as OpenSim. Unlike the male-specific OpenSim skeletal model, SIMMA does not differentiate gait results based on sex. The system requires no markers, allows dynamic camera movement with the subject, and is insensitive to the camera's position relative to the subject, provided the subject remains fully visible without occlusion. Tight-fitting clothing is recommended for optimal performance. The presence of assistive devices is accommodated, and the recording environment does not significantly impact results; however, the presence of another individual may affect gait outcomes. A limitation of this validation study is the lack of evaluation in environments with significant visual obstructions. In conclusion, SIMMA offers an accessible, reliable alternative to traditional MoCap, bridging laboratory-based protocols and practical clinical applications.

SIGNIFICANCE/CLINICAL RELEVANCE: By eliminating the need for expensive equipment and specialized facilities, SIMMA has the potential to integrate objective, accurate gait analysis into routine clinical practice. This accessibility could enhance patient monitoring in clinics, at home, and in sports performance environments, facilitating more personalized and effective interventions in musculoskeletal diagnostics, rehabilitation, and therapeutic monitoring.

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