A Measurement Concept to Collect Running Data in the Real World

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1 Introduction

Previous studies have extensively examined biomechanical locomotion and human adaptability in both able-bodied individuals [1–5] and prosthetic users [5–7]. However, most of these investigations have taken place in controlled, ”ideal” laboratory settings, often relying on fixated force plates and treadmills. While these methods provide precise and repeatable measurements, they may oversimplify the complexities of real-world movement, where individuals must continuously adapt to unpredictable conditions. Scholars have emphasized the importance of variability and adaptation in movement [8, 9], particularly the role of sensorimotor noise and its effects on motor control. Laboratory experiments minimize external variability by eliminating unexpected terrain changes, environmental disturbances (e.g., wind), and cognitive distractions. This creates a predictable environment, which may not accurately reflect how individuals, especially prosthetic users, adapt their movements under real-world conditions.

To address this gap, our study examines biomechanical adaptations in real-world conditions. By analyzing prosthetic users in outdoor settings, we aim to capture the natural variability and dynamic adjustments that occur during running. This approach allows us to consider adaptability, environmental disturbances, and situational unpredictability, offering insights that are more representative of actual performance.

2 Method

2.1 Study Design

As a proof of concept, one male participant (26 years old, 170 cm, 63 kg) with bilateral transtibial amputation took part in the study. He was an untrained runner and used his own prosthetic device, the *Össur Pro-Flex Terra* foot component.

The study was conducted as a field experiment on flat asphalt on an 800 m long road segment in a rural area. The running sequence took place between 18:00 and 18:30 under a temperature of 7°C, with winds of 13 km/h. To ensure continuous data transmission from the measurement devices, a vehicle followed the participant throughout the run, maintaining a stable connection between the wireless sensors and the recording equipment. The vehicle was kept at a safe and consistent distance to minimize any potential influence on the participant’s running behavior.

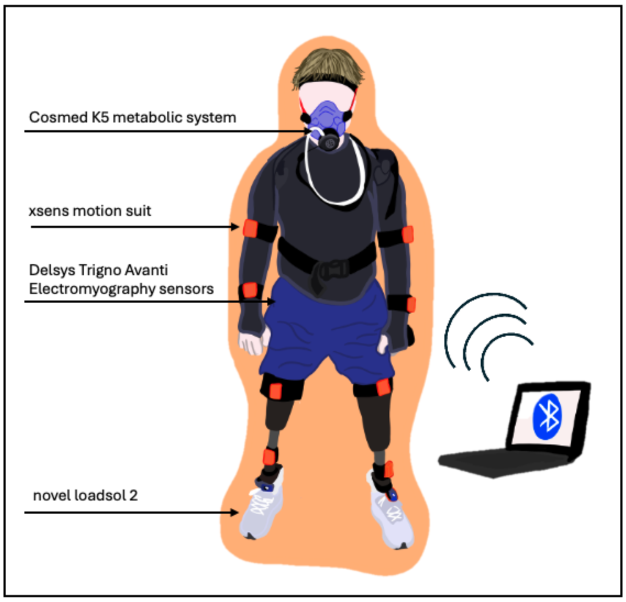

Figure 1: Schematic of the portable measurement equipment used.

The participant completed a fifteen-minute running sequence at a self-selected speed. Before the run, he described his assumed running strategy and expectations regarding movement patterns. After completing the sequence, he reflected on his initial expectations, reported any challenges encountered, and described his movement experience. These descriptions were recorded and transcribed for comparison with the measured biomechanical data.

2.2 Measurements

As depicted in Figure 1, we used a Cosmed K5 metabolic system to measure oxygen consumption (VO_2), carbon dioxide production (VCO_2), and the respiratory quotient (R). To record the range of motion of the legs and torso, an xsens motion suit was used. Muscular activity was monitored using Delsys Trigno Avanti electromyography sensors. The following muscles were considered: *M. Gluteus Maximus*, *M. Tensor Fasciae Latae*, *M. Rectus Femoris*, *M. Biceps Femoris*, *M. Vastus Medialis*. Additionally, novel loadsol 2 force measurement insoles were used to assess step frequency and force distribution between the fore- and backfoot.

3 Illustrative Results

3.1 Participant's Transcripts

The transcriptions provided valuable qualitative data, allowing us to analyze differences between the participant's expected and actual running strategies. When compared with measured biomechanical parameters, these insights revealed how the participant's perception of movement aligned or diverged from recorded data. Key difference were identified across three main areas: challenges during running, compensatory movements and running patterns.

The participant initially anticipated that his primary challenges would stem from anatomical constraints, specifically the absence of ligaments and differences in stump sizes. Additionally, he foresaw technical difficulties, particularly asymmetry in his gait mechanics. However, the observed challenges confirmed that while these anatomical limitations indeed played a role, stiffness leading to back pain emerged as an additional, unanticipated difficulty. Furthermore, the participant reported experiencing a mental load component, as his awareness of pain remained persistent throughout the run. This focus on discomfort may have influenced his running strategy and movement adaptations.

In terms of compensatory movements, the participant assumed that he would rely on increased arm movement and that he would engage his hips more actively to compensate for his gait asymmetry. The reflected transcripts, however, showed that arm movements were not only increased but also amplified during acceleration. Moreover, additional shoulder movements were perceived, which the participant had not previously considered. Notably, postural adjustments were also evident, with the gluteus maximus protruding outward.

With respect to the participant's running pattern, he predicted that his movement would consist of a hopping motion from the left to the right leg, which was confirmed, as the hopping movement was recalled after the running sequence. No additional self-reported refinements or adjustments to this strategy were identified.

3.2 Exemplary biomechanical analysis

A preliminary analysis of the EMG data showed a side-difference between the left and right *Tensor Fasciae Latae* which fits the participant's expectation to use additional hip movements to counter the perceived lateral instability. The force data from the insoles and the records of the motion suit are expected to confirm this assessment and allow further insights into the lateral component as well as the overall kinematics.

4 Discussion and Conclusion

The results of this study will provide a novel perspective on running mechanics by examining movement patterns in a real-world context. Unlike laboratories that often have idealized conditions [10], our experiment accounts for natural variability, such as surface inconsistencies and environmental factors, offering a more comprehensive overview of running strategies and adaptability.

From a technical point, this proof of concept demonstrated a feasible solution to collect data during locomotion in the real world while still achieving a reasonable data quality. Additionally, the incorporation of self-reported movement perceptions allow us to conclude if other methods such as interviews could aid to identify individual's strategies, movement patterns and to understand the reasons behind these adaptations.

Future research could include patients with unilateral prosthetics to increase the sample size and applicability. Additionally, data comparison between laboratory trials and field trials could assist to demonstrate the quality and variability between the two settings.

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