Metabolic & Biomechanic Performance Analysis of Human Gait at Different Water Levels

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Polytechnic University of Puerto Rico - Undergraduate Research Program for Honor and Outstanding Students (URP-HOS) 2025 - 2026

INTRODUCTION

Walking is one of the most efficient forms of human locomotion; however, environmental conditions such as flooding alter normal gait mechanics by increasing drag forces, reducing stability, and requiring greater muscular effort. These biomechanical adaptations increase metabolic demand and reduce locomotor efficiency (Rupcich et al., 2023).

Puerto Rico is highly exposed to hurricanes, floods, and tsunami hazards, making it an ideal location to investigate how water depth influences human movement (Puerto Rico Seismic Network, 2025). Understanding these physiological and biomechanical adaptations can improve emergency evacuation strategies and contribute to safer disaster response planning.

OBJECTIVE

Evaluate the metabolic and biomechanical performance of human gait under different water immersion levels compared to a previous work.

METHODOLOGY

1 **Participant Recruiment**

Four healthy Biomedical Engineering students will participate voluntarily after providing informed consent. Anthropometric measurements will be recorded to determine the appropriate immersion depths for each participant and to standardize the experimental conditions.

2 **Experimental Setup**

Testing will be conducted in a controlled swimming pool environment under four walking conditions: dry land, ankle-depth, knee-depth, and waist-depth water. A portable VO_2 Master metabolic analyzer, synchronized video cameras, measuring tape, and stopwatch will be used throughout the experiment.

3 **Walking Protocol**

Each participant will complete a standardized Six-Minute Walk Test (6MWT) consisting of one minute standing, one minute seated, six minutes of walking, and eight minutes of recovery. The complete protocol will be repeated five times under every experimental condition to improve measurement reliability.

4 **Data Acquisition**

Physiological variables including oxygen consumption (VO_2) and oxygen cost will be continuously recorded. Simultaneously, frontal and lateral video recordings will capture gait characteristics such as cadence, walking speed, step length, and foot contact events.

5 **Data Analysis**

Metabolic and biomechanical variables will be compared across all immersion levels using statistical analysis. Observational gait analysis will identify compensatory movement patterns associated with increasing water depth, allowing relationships between water immersion and locomotor performance to be established.

METABOLIC & OBSERVATIONAL DATA

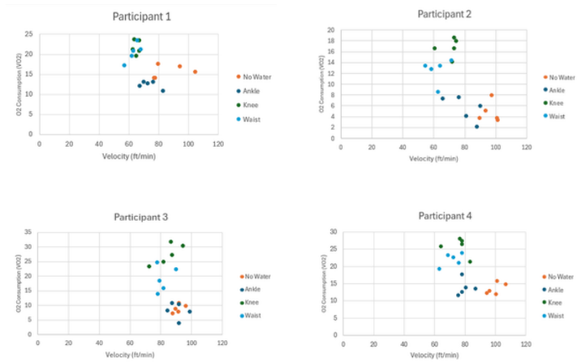


Figure 1. O2 Consumption vs. Velocity Chart for each participant.

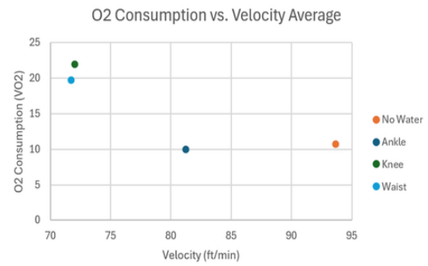


Figure 2. O2 Consumption vs. Velocity Average Between Participants Chart.



Figure 3. Observational analysis for heel strike at no water level – Sagittal and coronal views.



Figure 4. Observational analysis for heel strike at waist level – Sagittal and coronal views.

ANALYSIS AND RESULTS

Experimental data was analyzed by comparing walking velocity and oxygen consumption across dry, ankle-, knee-, and waist-depth conditions. The results showed a general reduction in walking velocity as water depth increased. Oxygen-consumption measurements also changed across immersion levels, demonstrating differences in metabolic response between walking conditions.

Underwater video recordings were used to complement the metabolic data. Frame-by-frame observation showed changes in the gait cycle and stepping behavior, with greater lower-limb flexion becoming visible at deeper water levels. These observations provided a biomechanical explanation for the differences identified in the performance measurements.

CONCLUSIONS

Increasing water depth affected both the metabolic and biomechanical performance of human gait. Deeper immersion was associated with reduced walking speed, changes in metabolic demand, and more pronounced gait adaptations, including greater knee flexion and altered stepping patterns. These results are consistent with previous findings and demonstrate the importance of considering water depth when evaluating human mobility during flood and tsunami evacuation scenarios.

FUTURE WORK

Future research should expand the number and diversity of participants to strengthen the applicability of the findings. Additionally, may also incorporate controlled moving-water conditions to better simulate realistic flood and tsunami environments and evaluate their effect on metabolic demand and gait stability.

ACKNOWLEDGEMENTS

I gratefully acknowledge Prof. Ricardo Bravo and Dr. Gustavo Pacheco-Crosetti for their mentorship and guidance throughout this research. Special thanks are extended to the Polytechnic University of Puerto Rico, the Undergraduate Research Program for Honor and Outstanding Students (URP-HOS), and the HSI STEM Grant for their support. I also thank Janice Mercado, Jean Barreto, and Gabriel Contreras for their participation and valuable contribution to the experimental trials. Finally, I would like to express my sincere appreciation to my family and friends for their continuous encouragement and support throughout this research.

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