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## Abstract

Inclined walking and running are widely used in athletic training and rehabilitation, yet their combined effects on oxygen consumption (VO<sub>2</sub>) and plantar pressure are not fully quantified. Uphill running (4.2 mph) at a 10% slope can reduce vertical loading rate by about 59% compared to level running (7.5 mph) at the same metabolic demand, suggesting potential benefits for reducing impact forces but with higher energy cost. Understanding this trade-off is essential for designing effective training, injury prevention, and rehabilitation programs. This study examines VO<sub>2</sub> and plantar pressure changes across two speeds (3.0 mph, 6.0 mph) and two inclines (0%, 10%). VO<sub>2</sub> was measured using the VO<sub>2</sub> Master analyzer, and plantar pressure with the Tekscan system. Five trials per condition were conducted in a single-subject design. Results showed a VO<sub>2</sub> increase of approximately 73% for walking and 33% for running when moving from 0% to 10% slope, accompanied by corresponding rises in energy cost. Plantar pressure shifted toward the forefoot at 10% incline, while 0% slope maintained a more even distribution. These findings provide relevant data to support performance optimization and rehabilitation strategies.

## Introduction

Physical activities such as walking and running are among the most common movements performed daily, yet the biomechanical and physiological responses—especially on inclined terrain—are not fully understood. Plantar pressure, the distribution of force exerted on the foot sole, plays a critical role in gait efficiency and comfort, while oxygen consumption (VO<sub>2</sub>) is a key measure of metabolic demand. Both variables are affected by speed, incline, and gait mechanics. The oxygen consumption increases notably with slope, as steeper inclines require greater muscular effort to overcome gravity. Higher plantar pressures can contribute to muscle fatigue and have significant clinical implications for the management of plantar tissue injury and metatarsal stress fracture risk. Dynamic plantar pressure analysis has also been shown to assist clinicians in making treatment decisions. Understanding how these variables interact is important for optimizing training, improving rehabilitation protocols, and preventing injuries. This study compares VO<sub>2</sub> and plantar pressure patterns during walking at 3.0 mph (80.47 m/min) and running at 6.0 mph (160.9 m/min) on both 0% and 10% slopes, aiming to identify how incline and speed together influence biomechanical and metabolic responses.

## Objectives

- Quantify VO<sub>2</sub> during walking and running at two slopes (0% and 10%).
- Measure plantar pressure distribution under the same conditions.
- Compare biomechanical and metabolic changes between speeds (3.0 mph and 6.0 mph) and inclines.
- Identify patterns in plantar pressure shift with slope variation.
- Provide data relevant to sports medicine, injury prevention, rehabilitation program design and the footwear industry.
- Incorporate biomedical equipment such as gait analysis and metabolic measurement devices for precise data collection.
- Study the interaction between cardiovascular, muscular, and biomechanical systems in response to incline.

## Methodology

- Participant:** Single-subject case study, 21-year-old male, above-average fitness, no gait abnormalities.
- Conditions:** Four scenarios tested — 3.0 mph (walking) and 6.0 mph (running) at 0% and 10% slopes.
- Trials:** 5 repetitions per condition for VO<sub>2</sub> measurements.
- Data Collection:** VO<sub>2</sub> recorded in all 5 trials per condition using the VO<sub>2</sub> Master analyzer; plantar pressure measured once per condition using the Tekscan in-shoe system.
- Equipment:** VO<sub>2</sub> Master analyzer, Tekscan system, treadmill for controlled speed/incline.



Figure 1. Equipment used for the research - Tekscan & VO<sub>2</sub> Master Metabolic Analyzer

## Data

Table 1. VO<sub>2</sub> & Energy Cost Averages

	80.47 m/min		160.9 m/min	
	VO <sub>2</sub>	Energy Cost	VO <sub>2</sub>	Energy Cost
0%	18.95 ± 0.6000	0.2354 ± 0.007456	43.96 ± 1.055	0.5463 ± 0.01311
10%	32.82 ± 1.343	0.4078 ± 0.01669	58.68 ± 6.164	0.7292 ± 0.07660

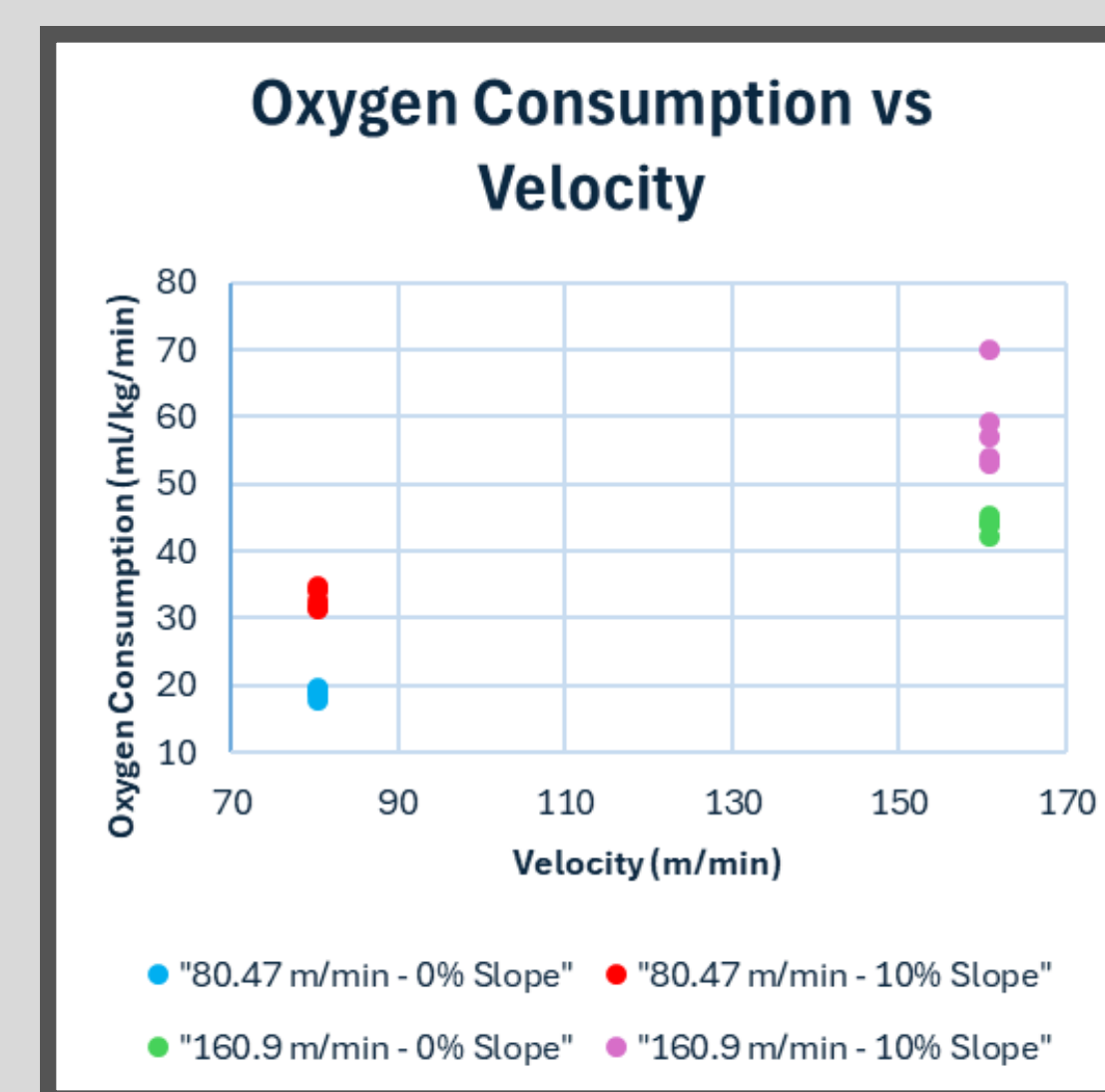


Figure 2. Oxygen Consumption vs Velocity

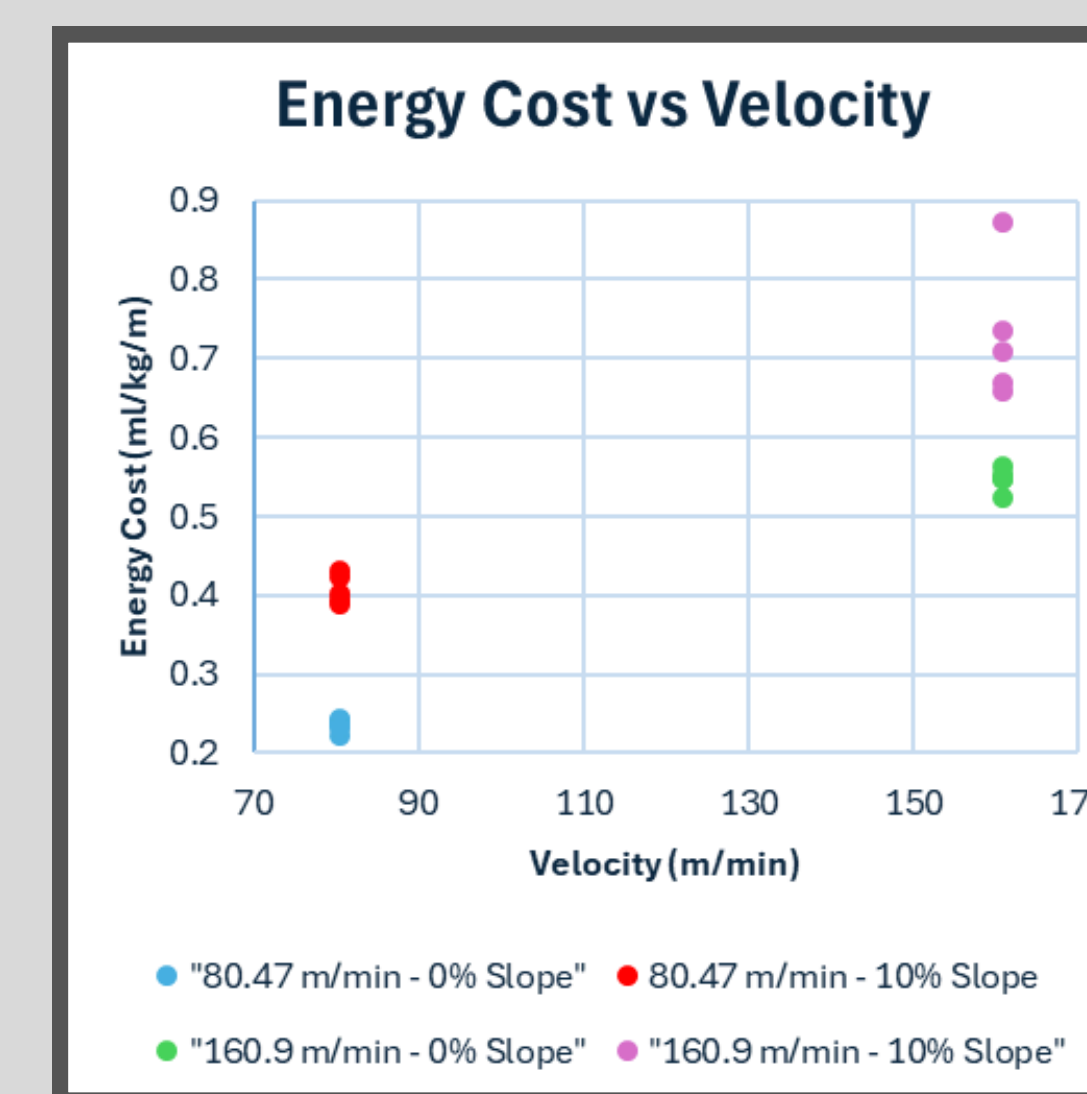


Figure 3. Energy Cost vs Velocity

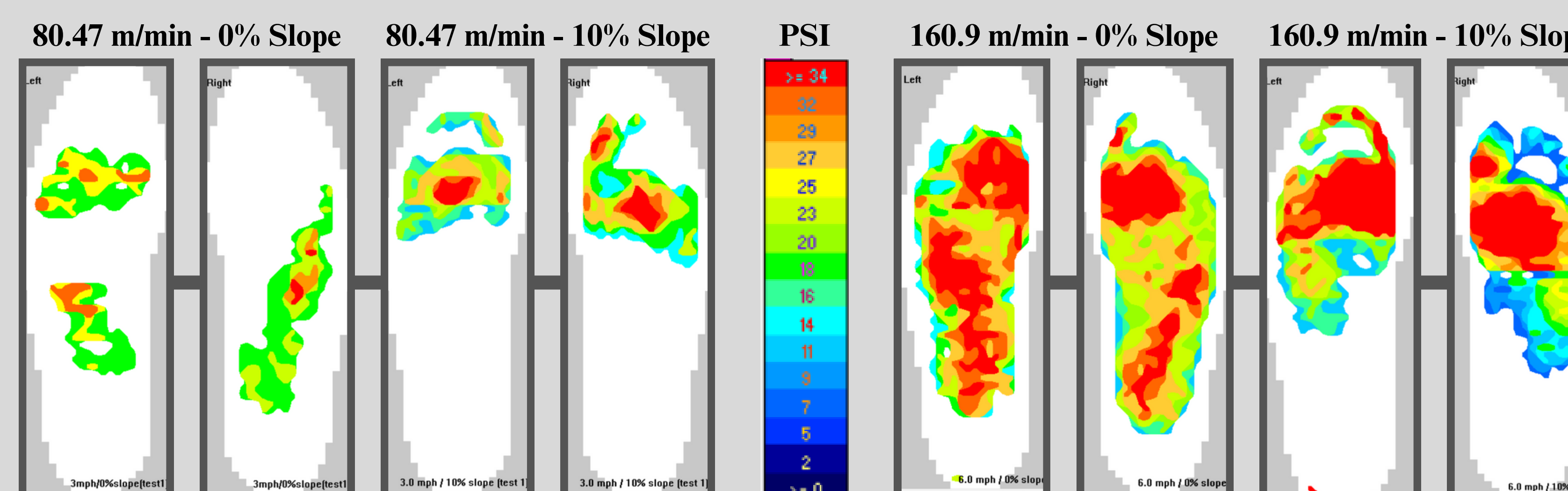


Figure 4. Tekscan - Plantar Pressure Map with Scale

## Analysis & Results

Analysis of VO<sub>2</sub> data revealed clear increases with both slope and speed. Walking at 3.0 mph showed a 73% rise in VO<sub>2</sub> when moving from 0% to 10% slope, while running at 6.0 mph showed a 33% increase under the same conditions. Energy cost followed the same trend, with the highest values observed during running at 10% incline. The data also suggest that similar metabolic demands can be achieved by combining a slower pace with a steeper incline or a faster pace with a lower incline, offering flexibility in training and rehabilitation program design. Plantar pressure maps demonstrated a distinct forward shift in load distribution at 10% slope, with greater emphasis on the forefoot and hallux regions, while 0% slope displayed a more balanced distribution across the foot. These findings indicate that steeper inclines substantially increase metabolic demand and alter foot loading patterns, potentially affecting performance, fatigue, and injury risk.

## Conclusions & Recommendations

This study confirmed that slope and speed significantly influence VO<sub>2</sub> and plantar pressure during walking and running. Steeper inclines increased metabolic demand and shifted plantar pressure toward the forefoot and hallux, while level terrain maintained a more balanced load distribution. Based on these findings, it is recommended to use more durable versions of Tekscan in-shoe sensors for higher-intensity testing, allowing for multiple uses without compromising accuracy. Adequate rest periods should be incorporated between trials to minimize fatigue effects on performance and data quality. Future research may benefit from collecting multiple plantar pressure recordings per condition to improve reliability and better capture variability in foot loading patterns.

## Future Work

- Add a jogging test and intermediate slope (5%) to study transitional conditions between walking and running.
- Perform tests on different terrains such as outdoor tracks, trails, and variable surfaces.
- Expand participant pool to include a wider range of ages, fitness levels, and gait patterns.

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