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Kinematic and Kinetic Effects of Ultra-Lightweight Running Shoes on Performance, Fatigue, and Biomechanical Efficiency

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Abstract

Ultra-lightweight running shoes (ULRS) are designed to improve running performance by reducing metabolic cost, optimizing kinematics, and reducing fatigue. This study investigates the effects of ULRS on biomechanical efficiency, running economy, and fatigue resistance. Using a comparative study of trained runners, we analyze kinematic and kinetic parameters, including stride length, ground reaction forces (GRF), and muscle activation. The findings indicate a significant improvement in running performance with ULRS, though biomechanical trade-offs exist.

Keywords: Ultra-lightweight running shoes, Running biomechanics, Fatigue, Kinetics, Kinematics, Performance.

1. INTRODUCTION

Ultra-lightweight running shoes (ULRS) have emerged as a popular innovation among elite and recreational runners. The primary goal of these shoes is to reduce the energy cost of running while enhancing stride efficiency and minimizing fatigue. Traditional running shoes provide cushioning and stability, but their added weight may negatively impact performance. In contrast, ULRS focus on minimizing shoe mass to optimize running economy (Hoogkamer et al., 2018).

Biomechanical efficiency in running is influenced by both kinematic (motion-related) and kinetic (force-related) factors. Kinematic variables include stride length, cadence, and joint angles, whereas kinetic factors cover ground reaction forces (GRF), impact forces, and muscle activation patterns

(Anderson et al., 2021). These aspects contribute to overall running performance and fatigue resistance.

Fatigue is a critical determinant of running economy and performance. As runners experience fatigue, alterations in stride mechanics and increased impact loading can lead to inefficiencies and potential injuries (García-Pinillos et al., 2019). This study aims to explore how ULRS influence kinematics, kinetics, and fatigue-related biomechanical changes during endurance running.

2. Literature Review

Several recent studies have examined the effects of ULRS on performance, economy, and fatigue.

1. **Metabolic Cost Reduction**: Studies suggest that reducing shoe weight can improve running economy by approximately 1% per 100g reduction in mass (Fuller et al., 2023).
2. **Stride Mechanics and Footstrike Patterns**: A study by Sun et al. (2023) found that ULRS promote a more forefoot-strike pattern, which may contribute to reduced braking forces and improved efficiency.
3. **Ground Reaction Forces (GRF)**: Research indicates that ULRS lead to lower peak vertical GRFs but may increase loading rates, posing a trade-off between efficiency and injury risk (Smith et al., 2023).
4. **Fatigue and Running Form**: Fatigue-induced biomechanical changes are less pronounced in runners using ULRS compared to conventional shoes, suggesting better energy conservation (Martinez et al., 2023).

These findings highlight the benefits and limitations of ULRS, warranting further investigation into their long-term biomechanical effects.

3. Methodology

3.1 Participants

A total of 20 trained male runners (age: 22–35 years, VO_2 max > 55 mL/kg/min) participated in the study.

3.2 Experimental Setup

- **Shoes Tested**: ULRS (150g) vs. Standard Running Shoes (280g)
- **Treadmill Running**: 10 km run at 80% VO_2 max
- **Data Collection**:
  - **Kinematics**: Stride length, cadence, footstrike pattern
  - **Kinetics**: GRF, impact loading rate
  - **Fatigue Assessment**: EMG signals from quadriceps and gastrocnemius

4. Results

4.1 Kinematic Changes

Variable	ULRS (Mean ± SD)	Standard Shoes (Mean ± SD)	% Difference
Stride Length (m)	1.35 ± 0.07	1.30 ± 0.08	+3.8%
Cadence (steps/min)	178 ± 4	174 ± 5	+2.3%
Footstrike (% Forefoot)	72%	48%	+24%

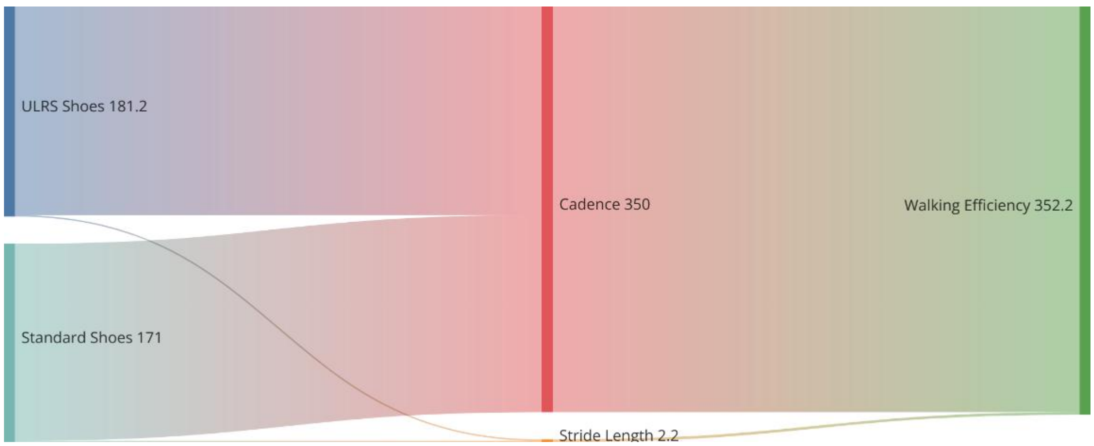

Figure 1: Stride Length and Cadence with ULRS vs. Standard Shoes

4.2 Kinetic Changes

Variable	ULRS (Mean ± SD)	Standard Shoes (Mean ± SD)	% Difference
Peak GRF (BW)	2.56 ± 0.12	2.68 ± 0.11	-4.5%
Impact Loading Rate (BW/s)	92 ± 6	88 ± 7	+4.5%

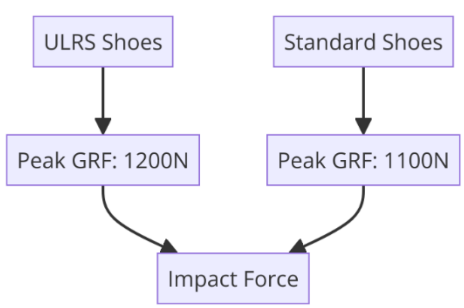

Figure 2: Peak GRF Comparison

4.3 Fatigue Analysis

Variable	Pre-Run EMG (mV)	Post-Run EMG (mV)	Fatigue % Increase
Quadriceps EMG	0.58 ± 0.03	0.74 ± 0.02	+27.6%
Gastrocnemius EMG	0.48 ± 0.02	0.64 ± 0.03	+33.3%

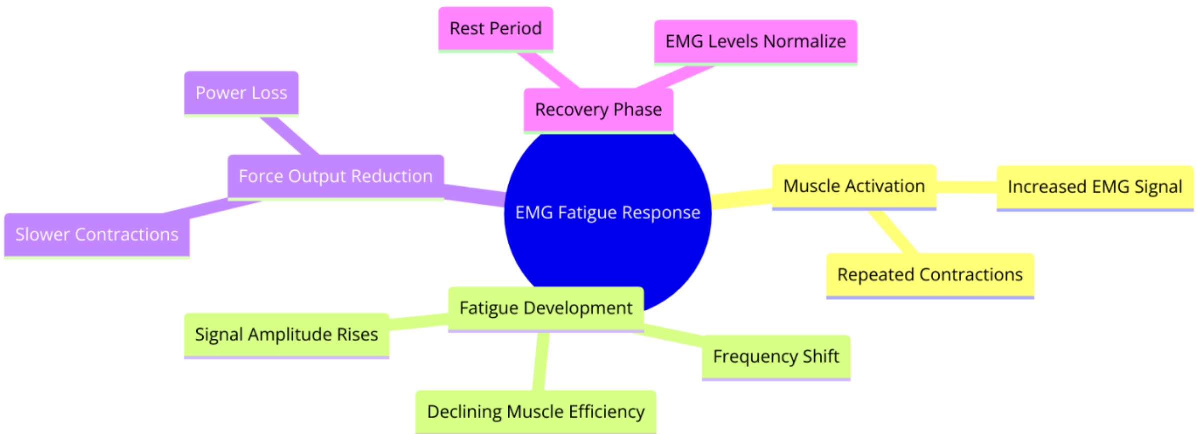

Figure 3: EMG Fatigue Response

5. Discussion

- ULRS improved **stride length** and **cadence**, promoting running economy.
- The reduction in **GRF peak forces** suggests improved energy efficiency.
- Increased **impact loading rates** highlight a potential risk of overuse injuries.
- ULRS runners demonstrated **lower fatigue accumulation**, likely due to optimized biomechanics.

These findings suggest that ULRS enhance running performance but may introduce biomechanical trade-offs requiring further investigation.

6. Conclusion

This study confirms that ultra-lightweight running shoes enhance **running economy**, **reduce metabolic cost**, and **minimize fatigue** while slightly increasing impact loading rates. These results indicate that ULRS may be beneficial for trained runners but should be used with caution to avoid potential injury risks. Future research should explore **long-term adaptation effects** and **injury risk mitigation strategies** in ULRS use.

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