Durability in Endurance Exercise: Concept, History, and Applications for Trail Running

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Introduction

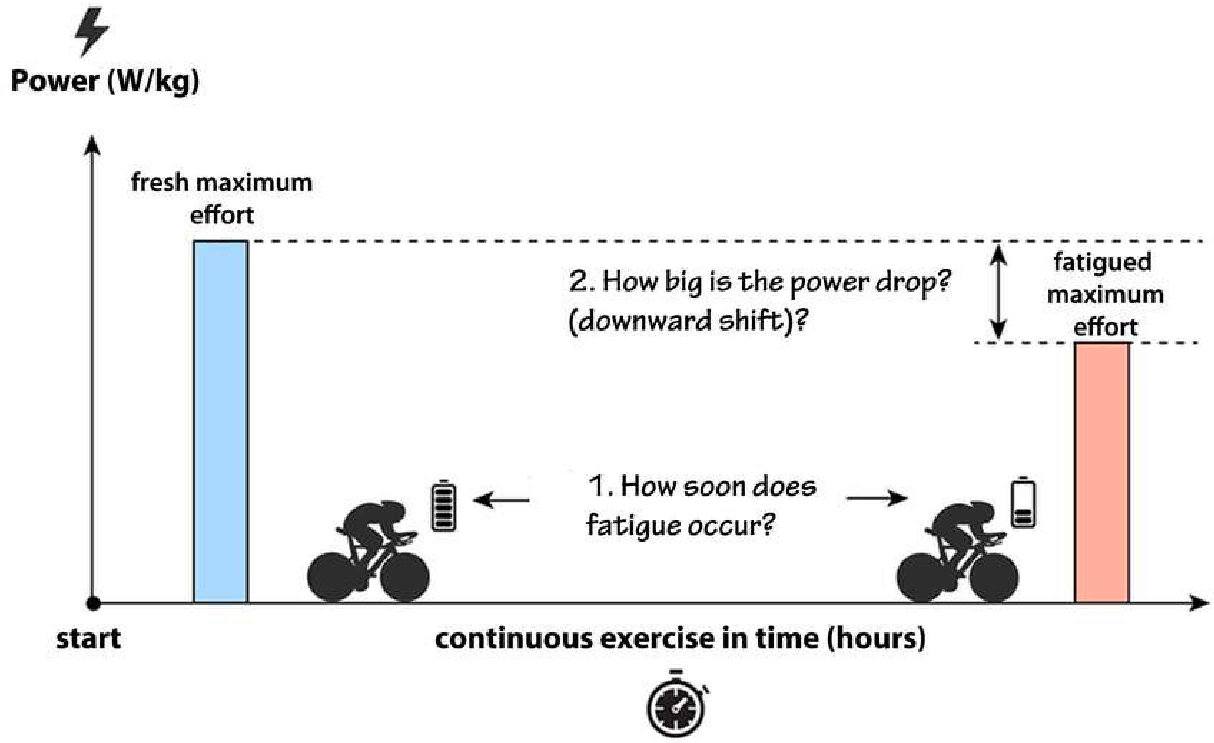
For decades, endurance performance has largely been interpreted through three key physiological pillars: maximal oxygen uptake (VO_2max), lactate or anaerobic threshold, and movement economy (Joyner et al., 2008). These "big three" have served as a reliable foundation for endurance profiling, yet they share a critical limitation: they are almost always measured in a non-fatigued, *fresh* state. This overlooks the reality that the defining challenge in endurance sports is not how an athlete performs at the outset, but how well they resist the gradual decline in physiological function that occurs over time (Maunder et al., 2021; Hunter et al., 2025). During prolonged exercise, physiological variables frequently decline. This recognition has led to the emergence of a new construct in exercise science—*durability*, a concept that captures an athlete's capacity to maintain physiological stability and performance during prolonged exertion. As endurance events grow longer and more demanding, durability has become increasingly essential for understanding real-world athletic performance.

Key Points

- Durability describes how quickly and to what extent an athlete's physiological systems deteriorate during prolonged exercise—adding a critical dimension beyond VO_2max, threshold, and economy.
- In trail and ultra-endurance events, durability is decisive: athletes with greater durability maintain pace, coordination, running economy, and cognitive function for longer periods.
- Durability can be trained through high-volume endurance work, terrain-specific stressors such as downhill running, and training structures that expose the athlete to cumulative fatigue.
- Durability can be assessed with simple field indicators such as heart-rate–power drift, and is supported by race-based data showing marked neuromuscular fatigue during long mountain ultramarathons.

Definition of Durability in Current Scientific Use

Durability has been formally described as *the time of onset and magnitude of deterioration in physiological-profiling characteristics during prolonged exercise* (Maunder et al., 2021) and as *the resilience to the deterioration of physiological variables and performance either during or after extended periods of exercise* (Hunter et al., 2025). These characteristics encompass ventilatory and lactate thresholds, oxygen uptake (VO_2) kinetics, mechanical efficiency, and heart-rate drift. Unlike acute fatigue, which is typically tied to intense short-duration efforts, durability concerns the slow erosion of performance even when intensity remains constant. Quantifying durability presents methodological challenges, as ongoing research indicates. Specifically, controlling factors like environmental conditions, nutrition, and training load are crucial because they can either obscure or intensify fatigue-related changes.



Durability, as defined by Maunder et al. (2021), refers to: " ..time of onset and magnitude of deterioration in physiological characteristics over time during prolonged exercise." - This visual representation of durability, adapted from Bonnevie-Svendsen (2023)

Durability versus Resilience

Although durability describes the stability of physiological variables during a continuous, prolonged effort, resilience reflects a distinct yet complementary quality. Based on the framework outlined by Meixner et al. (2025), resilience refers to the capacity to maintain or regain physiological and mechanical function when exposed to repeated or fluctuating stressors. These perturbations may include environmental extremes (heat, cold, altitude), technical demands (steep climbs, descents, uneven terrain), or intermittent surges in power output. In practice, durability governs how well an athlete maintains performance during a steady, uninterrupted effort, whereas resilience describes how effectively they preserve or restore function when the exercise demands vary. Both traits contribute meaningfully to performance in trail and ultra-endurance events, where terrain and environmental conditions repeatedly stress the athlete.

Historical Antecedents

Although the specific term *durability* is new, the physiological processes underlying it have long been observed. Early work on cardiovascular drift showed that during steady-state exercise, heart rate rises and stroke volume falls over time (Coyle & González-Alonso, 2001). Research on VO_2 kinetics demonstrated that oxygen uptake drifts upward during sustained heavy exercise, particularly when preceded by prior work (Burnley et al., 2002). Studies of running economy similarly showed that the oxygen cost of running deteriorates during prolonged efforts at a constant pace (Sproule, 1998). Each of these findings reflects different expressions of the same overarching phenomenon: a progressive decline in physiological efficiency during sustained exercise. The introduction of the durability construct unifies these strands under a single, performance-relevant framework.

Application to Endurance Athletes

In applied settings, durability helps explain why athletes with similar laboratory profiles may perform very differently in long events. For example, cyclists with greater durability—reflected in smaller declines in physiological thresholds after sustained submaximal work—maintain superior high-intensity output later in exercise (Hamilton et al., 2024). For endurance athletes across disciplines, durability is expressed through the ability to maintain threshold power or pace, preserve coordination and running economy, and limit physiological drift, meaning their heart rate, perceived effort, and efficiency stay stable for hours rather than just minutes. It is closely linked to pacing effectiveness, finishing speed, and the capacity to avoid late-race performance collapse.

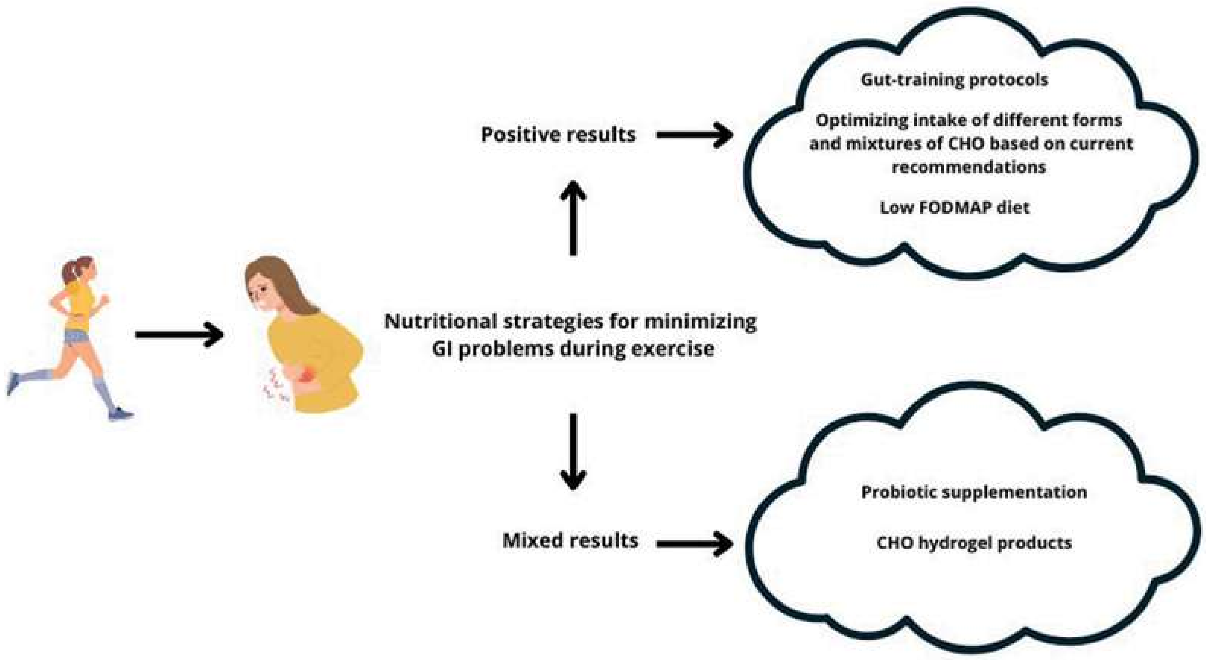
Training for Durability with a Focus on Trail Running

Developing durability requires more than elevating fresh-state performance markers. Matomäki et al. (2023) demonstrated that durability is highly trainable and that both low-intensity aerobic volume and high-intensity interval training independently improve durability, with a combined approach producing the greatest gains. Long sessions remain the backbone of durability development, while intervals introduce potent stressors that reinforce aerobic and neuromuscular robustness. Nutrition and hydration strategies—especially those that support glycogen availability and thermoregulation—are essential for maintaining steady physiological function during extended activity (Romijn et al., 1993; Coyle & González-Alonso, 2001).

Trail running introduces additional layers: metabolic, mechanical, neuromuscular, and technical. Downhill running produces large eccentric loads on the quadriceps and calves, often leading to muscle damage, reduced contractile function, and neuromuscular fatigue (Eston et al., 1995; Bontemps et al., 2020). Repeated exposure to technical terrain, steep climbs, variable gradients, and prolonged descents develops mechanical robustness and movement efficiency specific to trail demands. Back-to-back long runs and multi-day blocks or “shock weekends” with long climbs/descents recreate the cumulative fatigue of long trail races and reinforce the athlete's ability to maintain coordination, economy, and stability as fatigue accumulates (Millet & Nicot, 2017). The most durable trail runners are those who retain technical proficiency when fatigued—particularly in late-race downhill sections, where races are often won or lost.

Repeated Bout Effect

A central concept in durability—particularly for trail athletes—is the repeated bout effect (RBE). This describes how a single bout of eccentric exercise reduces muscle damage and performance loss during subsequent bouts. Downhill running is a highly effective way to induce the RBE through neural adaptations, structural remodeling, and cellular protective changes (McHugh, 2003). Evidence shows that even one downhill session can meaningfully reduce strength loss and fatigue during subsequent efforts (Assumpção et al., 2020). For trail runners, systematically incorporating downhill running not only improves descending skill but also enhances neuromuscular resilience and may reduce injury risk late in long events.



Graphical abstract of nutritional strategies for minimizing GI problems during exercise.
Source: Mlinarič & Mohorko (2025).

The Role of Nutrition

Nutrition is deeply intertwined with durability. Carbohydrate availability is a major determinant of metabolic and neuromuscular stability during prolonged work. As glycogen becomes depleted, running economy worsens, perceived exertion rises, and the decline in performance accelerates

(Romijn et al., 1993; Burke et al., 2011). Consuming 60–90 $g \cdot h^{-1}$ of carbohydrates—preferably using multiple transportable sources—helps stabilize blood glucose and delays fatigue, supporting better late-race pacing (Jeukendrup, 2014; Cermak et al., 2013). Hydration is similarly important, as dehydration increases cardiovascular strain and core temperature, accelerating heart-rate drift and undermining durability (Coyle & González-Alonso, 2001).

In trail and ultra events, fueling demands are often complicated by gastrointestinal distress and considerable sodium losses. Gut-training strategies can improve carbohydrate tolerance and reduce GI symptoms, enabling athletes to maintain higher fueling rates with fewer disruptions (Mlinarič & Mohorko, 2025). At the same time, adequate sodium replacement—typically 300–700 $mg \cdot h^{-1}$ depending on sweat rate—helps sustain fluid balance, hydration status, and neuromuscular function during long-duration efforts (Costa et al., 2013; Hew-Butler et al., 2015). Together, these nutrition strategies support cognitive clarity, movement quality, and overall performance capacity deep into an ultra-endurance event, making nutrition a critical pillar of durability.

Measurement and Methodological Considerations

Durability can be assessed in the lab through long (2–3 hour) submaximal sessions followed by repeated physiological profiling, such as lactate threshold or critical power assessments (Hunter et al., 2025). Field-based measures include heart-rate–power decoupling, pace-to-heart-rate drift, and consistency during long runs. While these methods offer practical insights, they require careful control of confounding factors such as nutrition, temperature, and hydration to ensure valid interpretation.

Real-world data reinforce these controlled observations. Fieldwork from Millet's group during the 330-km Tor des Géants ultramarathon demonstrated marked reductions in maximal voluntary contraction and substantial neuromuscular fatigue, based on testing conducted immediately before and after the event (Saugy et al., 2013). These findings highlight the degree of multi-system deterioration that occurs under authentic mountain ultra-endurance conditions and help bridge the gap between laboratory results and the complex physiological demands of competitive trail running.

Future Directions

Durability research remains young. Key open questions include how durability develops across the lifespan and how trainable it is relative to genetic influences. Early evidence suggests that durability may decline differently than VO_2max with aging, highlighting its importance for masters athletes (Maunder et al., 2021).

Summary and Conclusion

Durability has become a crucial addition to the endurance performance profile, shifting the focus from how high an athlete's physiological ceiling is to how long it can be sustained under fatigue. In trail and ultra-endurance events, durability often determines late-race performance. Training that combines sufficient volume, structured intensity, terrain-specific stressors such as downhill running, and effective nutrition appears most effective for improving durability. As the field evolves, durability may join VO_2max, threshold, and economy as a central component of endurance profiling.

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