Real-Time Estimation of Muscular Efficiency in Cycling Using Garmin Devices

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Résumé

Introduction
Muscular efficiency-the ratio of mechanical power output to metabolic energy expenditure-is a crucial performance metric in cycling. Traditional laboratory-based assessments are impractical for field use. Modern wearable technology, particularly Garmin devices equipped with power meters, enables real-time efficiency estimation by correlating heart rate (HR) with power output. This study presents a novel metric for monitoring muscular efficiency variations during outdoor cycling, validated through professional athlete data and field testing.

Method

Data Acquisition and Processing.

The metric integrates data from HR monitors and power meters. Initial validation used retrospective data from professional cyclists (Jorgenson, Powless, van der Poel) via Strava (October 2022). Efficiency is calculated as:

Efficiency= Mechanical Energy (Power × Time) / Metabolic Energy (HR-derived)

Metabolic energy estimation incorporates individualized parameters (age, mass, sex) using validated models (Keytel et al., 2005). The metric was implemented via Garmin's SDK as a real-time data field.

Operational Range. Calculations are restricted to intensities between ventilatory threshold 1 and lactate threshold, where HR and power exhibit linearity (de Leeuw et al., 2025). Efficiency values are averaged over 1–3-minute stable HR intervals.

Results

Implementation and Validation.

*Intervenant

The metric was tested in blinded comparisons with perceived exertion and field-tested across tens of thousands of kilometers. Key findings:

Intra-session trends reliably reflected fatigue (declining efficiency) or optimal pacing (rising efficiency).

Absolute values varied with environmental conditions (temperature, altitude), but relative trends remained actionable.

Software Reliability.
The Garmin Connect IQ SDK exhibited limitations: inadequate documentation, lacking bug-prevention tools, and no formal modeling frameworks. Despite this, the data field maintained robust functionality during testing.

Observations and Patterns.

While absolute efficiency values varied across sessions due to environmental conditions (temperature, humidity, altitude), intra-session trends were informative. A decline in efficiency often indicated muscular fatigue. Conversely, an upward trend in efficiency suggested optimal pacing and favorable conditions.

Discussion

Utility of Real-Time Monitoring

The metric enables cyclists to adjust pacing, hydration, and nutrition mid-ride. For example, a 5% efficiency drop over 30 minutes may prompt reduced intensity to delay fatigue.

Limitations

HR variability: Stress, stimulants, and heat alter HR independently of workload.

Intensity thresholds: Linearity assumptions fail at extremes (e.g., sprinting or heat stress).

Platform constraints: Garmin's SDK lacks tools for rigorous error handling.

Comparative Advantages

Existing tools like SPHGraWH visualize HR/power but lack efficiency quantification (Garmin Forums, n.d.). Our metric integrates physiological and mechanical data into a single actionable index, akin to running's HR/speed ratio (Vesterinen et al., 2014).

Conclusions and Future Directions

This real-time efficiency metric is useful in endurance analytics, offering immediate feedback for training and racing. Future work should:

Expand validation to amateur athletes.

Integrate environmental sensors (e.g., temperature).

Develop cross-platform implementations to mitigate SDK limitations.

References

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