

**INTEGRATION OF PHYSICAL ENDURANCE AND COGNITIVE
RESILIENCE IN THE TRAINING OF PROFESSIONAL CYCLISTS**

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ABSTRACT

Prolonged endurance training in professional cycling increasingly requires the integration of physiological efficiency, neuromuscular stability, and cognitive resilience to meet race-specific demands. The purpose of this study was to evaluate the effectiveness of the author-developed Adaptive Rhythmic-Variable Endurance Training System (ARVETS), an original endurance training methodology integrating rhythmic workload variability, real-time neuromuscular correction, and cognitive-motor stimuli, in enhancing multidimensional endurance performance during long-duration cycling sessions. The study employed within-subject experimental design, continuous heart rate and power monitoring, Leg Balance Ratio (LBR) analysis, cadence variability assessment, and reaction time measurement to auditory stimuli under fatigue.

Following the ARVETS intervention, cyclists demonstrated reduced cardiovascular drift, reflected in a lower heart rate-to-power ratio during the second and third training hours, prolonged time sustained at 70–88% FTP, and improved aerobic stability. Neuromuscular asymmetry was significantly reduced, with peak LBR during the final training hour decreasing from 6.3% to 3.2% ($p < 0.05$), followed by faster correction to 2.7%. Cognitive resilience improved as fatigue-related reaction time slowing was attenuated by 30 ms compared to baseline steady-state training ($p < 0.05$).

The findings indicate that ARVETS promotes integrated physiological, neuromuscular, and cognitive adaptations rather than isolated performance gains. The scientific novelty lies in the unified endurance framework combining rhythmic variability, real-time neuromuscular correction, and cognitive load under fatigue. Future research should examine long-term competitive transfer effects and individualized ARVETS optimization strategies.

KEYWORDS

Cardiovascular drift, neuromuscular symmetry, reaction time, cadence variability, endurance stability, cognitive load

INTRODUCTION

Endurance performance in professional cycling is traditionally conceptualized as a function of physiological capacity, particularly aerobic power, metabolic efficiency, and fatigue resistance. Foundational research in endurance physiology has demonstrated that sustained power output depends

on the interaction between cardiovascular regulation, muscular efficiency, and energy system stability (Coyle et al., 1988; Seiler, 2010). These models have guided the widespread use of steady-state endurance training aimed at optimizing oxygen uptake, lactate thresholds, and cardiovascular efficiency. However, professional road racing increasingly exposes cyclists to prolonged workloads characterized by variable cadence, stochastic power demands, and continuous decision-making under fatigue, challenging the sufficiency of purely physiological training paradigms.

Recent studies indicate that prolonged endurance performance deteriorates not only due to metabolic limitations but also as a result of neuromuscular asymmetry, motor coordination decline, and cognitive fatigue (Abbiss & Laursen, 2012; Marcora et al., 2009). These findings suggest that endurance degradation is a multidimensional process involving physiological, neuromuscular, and cognitive mechanisms.

Contemporary training research increasingly emphasizes the role of cognitive resilience and attentional control during prolonged exercise. Mental fatigue has been shown to impair endurance performance independently of physiological markers, reducing tolerance to sustained workloads and slowing reaction times under fatigue (Marcora et al., 2009). In cycling, delayed decision-making and reduced motor responsiveness during the later stages of races may critically influence tactical execution and safety. Despite this evidence, most endurance training models continue to isolate physiological load from cognitive and neuromuscular demands, limiting their ecological validity for professional competition.

Empirical training approaches that systematically implement this integration within prolonged endurance cycling are still limited. In particular, structured methodologies that concurrently consider cardiovascular drift, neuromuscular symmetry, cadence adaptability, and cognitive resilience within a unified endurance framework are not yet sufficiently represented in the current literature.

Against this background, the Adaptive Rhythmic-Variable Endurance Training System (ARVETS) was developed as an original, author-designed endurance training methodology specifically intended for prolonged (3+ hour) cycling sessions. Unlike conventional steady-state or externally adjusted endurance models, ARVETS integrates structured rhythmic variability of power and cadence, continuous monitoring of pedaling asymmetry with threshold-based real-time correction, and embedded cognitive-motor stimuli applied under accumulated fatigue. This methodological integration is designed to produce combined physiological, neuromuscular, and cognitive endurance adaptations within a single training framework.

To address this gap, the present study introduces the Adaptive Rhythmic-Variable Endurance Training System (ARVETS), designed to integrate rhythmic power variability, real-time neuromuscular correction, and cognitive-motor stimuli during long-duration cycling sessions. By aligning physiological load with neuromuscular and cognitive demands, ARVETS seeks to enhance endurance stability under race-like conditions rather than optimize isolated performance components.

The purpose of this study was to evaluate the effectiveness of the Adaptive Rhythmic-Variable Endurance Training System (ARVETS) in improving integrated physiological, neuromuscular, and cognitive endurance performance in professional cyclists during prolonged cycling sessions.

Empirical objectives

1. To assess changes in cardiovascular drift and aerobic stability during prolonged cycling following ARVETS implementation.

2. To examine the effects of ARVETS on neuromuscular coordination, pedaling symmetry, and cadence adaptability under fatigue.
3. To evaluate cognitive resilience during prolonged endurance exercise using reaction time responses to auditory stimuli.

Research Hypothesis

It was hypothesized that ARVETS would improve endurance performance relative to baseline steady-state training by reducing cardiovascular drift, stabilizing neuromuscular coordination, and preserving cognitive reaction speed during prolonged cycling.

Literature review

Recent endurance-cycling scholarship increasingly treats performance as an interaction between physiological durability, biomechanical efficiency, and cognitive functioning under fatigue. This shift is important for professional cycling because late-race outcomes depend not only on aerobic capacity but also on the athlete's ability to preserve movement quality and make rapid decisions after prolonged load.

A first critical strand concerns **mental fatigue and the quality of sport-specific psychomotor execution**. Habay et al. (2021) systematically reviewed evidence showing that mental fatigue impairs sport-specific psychomotor performance across multiple sports, with frequent outcomes including slower responses and reduced precision in task execution. Their review supports a key implication for cycling: when fatigue is not only physical but also cognitive, athletes may preserve power yet lose responsiveness and motor timing – an issue that becomes decisive in the final hour of long events. Importantly, Habay et al. emphasize heterogeneity in tasks and measures, which limits direct translation into cycling-specific protocols and highlights the need for standardized, ecologically valid cognitive–motor assessments during endurance work.

A second strand advances from “mental fatigue exists” to **how it can be counteracted in athletes**. Sun et al. (2024a) reviewed interventions aimed at reducing mental fatigue and improving subsequent sport-specific outcomes, mapping practical strategies (e.g., recovery modalities and psychological approaches) while noting that intervention effectiveness varies substantially by task and sport context. This is useful for cycling because it frames cognitive resilience as trainable rather than merely a limiting factor. However, a limitation remains: most intervention studies are not embedded inside prolonged endurance sessions where physiological strain accumulates concurrently, meaning real-world cycling specificity is still underrepresented.

Relatedly, Sun et al. (2024b) provided a systematic review with meta-analysis on interventions addressing mental fatigue and their effects on sport-specific performance. While this work strengthens the evidence base by pooling results, it also indirectly exposes a methodological gap relevant to professional cycling: many interventions are tested before or after exercise rather than **integrated into the endurance session itself** as a combined cognitive–motor load. For cycling, where decisions and rapid motor adjustments occur under sustained effort, this suggests that a training model should embed cognitive stimuli during late-session fatigue rather than treating cognition as a separate “add-on.”

Cycling-specific reviews reinforce that endurance performance is constrained by **how the body holds form under prolonged workload**, not just by metabolic ceiling. Husband et al. (2024) systematically reviewed the impact of cycling position changes on biomechanical and physiological factors, showing

that positional variables can meaningfully alter efficiency, comfort, and physiological demand. This is directly relevant to endurance stability: even small biomechanical shifts can change load distribution and potentially magnify asymmetry when fatigue rises. Yet, the review focus is mainly on position optimization, not on real-time neuromuscular correction strategies during long sessions – leaving room for training systems that detect and correct fatigue-driven coordination drift while maintaining session flow.

Two contemporary reviews also sharpen the **durability** perspective in trained cyclists – i.e., how performance declines as fatigue accumulates. Sánchez-Jiménez et al. (2025) systematically examined how exercise intensity influences the work required to induce changes in cyclists' acute durability and discussed the suitability of work-based monitoring (kJ) for fatigue tracking. This aligns with the idea that fatigue effects are dose-dependent and must be quantified across time and intensity. However, durability reviews typically emphasize physiological monitoring and external load, with limited attention to how neuromuscular coordination and cognitive responsiveness degrade simultaneously – precisely the multidimensional gap your study targets.

Finally, endurance adaptation depends on **how training intensity is distributed over time**, especially in trained cyclists. Cove et al. (2025) conducted a systematic review with multilevel meta-analysis and meta-regression on training distribution/duration/volume and their effects on $VO_2\max$ and performance in trained cyclists. Their findings are central for structuring endurance development, but they also illustrate a practical limitation: intensity distribution models typically treat the athlete as a physiological system, while professional cycling demands stable motor control and decision readiness under fatigue-driven variability. In other words, “optimal distribution” does not automatically guarantee preserved symmetry, cadence control, or reaction speed late in a prolonged session.

Across reviews, there is broad agreement that (1) fatigue is multidimensional, (2) cognition can constrain performance, and (3) cycling outcomes depend on biomechanical and physiological efficiency under real conditions. Where the literature remains less developed is the **operational integration** of these components inside a single prolonged cycling protocol. Mental fatigue reviews call for more sport-specific, ecologically valid tasks; cycling biomechanics and durability reviews highlight measurable fatigue effects but rarely combine them with embedded cognitive stimuli and threshold-based neuromuscular correction; training distribution meta-analyses optimize endurance exposure but do not specify how to preserve coordination and reaction speed during late-session fatigue.

This convergence supports the logic of an integrated endurance framework (like ARVETS): rhythmic variability to model race dynamics, continuous monitoring to detect fatigue-induced coordination drift, and embedded cognitive–motor stimuli to train attentional stability and response speed under physiological strain. The most clear research gap – visible across the reviewed literature – is the shortage of **unified, session-embedded methodologies** that concurrently track cardiovascular drift, neuromuscular symmetry/coordination, cadence adaptability, and cognitive responsiveness during prolonged cycling.

Methods and Materials

Study procedure. The study employed a within-subject experimental design to evaluate the effects of the author-developed Adaptive Rhythmic-Variable Endurance Training System (ARVETS), an original endurance training methodology, on endurance performance during prolonged cycling

sessions. At the first stage, baseline measurements were collected during prolonged steady-state endurance cycling sessions exceeding three hours. These sessions were characterized by stable power output and cadence and served as the reference condition for subsequent comparisons. The second stage involved the implementation of the ARVETS protocol during prolonged cycling sessions of comparable duration. This protocol integrated rhythmic variability in power and cadence, threshold-based neuromuscular correction, and cognitively demanding auditory–motor tasks under sustained physiological fatigue. At the third stage, post-intervention measurements were obtained during ARVETS sessions using identical recording and analytical procedures. This design enabled direct within-subject comparisons between baseline steady-state and ARVETS training conditions across physiological, neuromuscular, and cognitive domains.

Methods. Four analytical methods were applied in accordance with the outcome variables reported in the Results section.

1. **Physiological endurance assessment.** Cardiovascular endurance stability was assessed through analysis of cardiovascular drift using the heart rate–to–power ratio (HR/W). Continuous heart rate and power output data were recorded throughout each training session. HR/W values were calculated across prolonged workloads, with specific emphasis on the second and third training hours, during which fatigue-related cardiovascular drift is most pronounced.
2. **Neuromuscular symmetry analysis.** Neuromuscular coordination was evaluated using the Leg Balance Ratio (LBR), defined as the percentage difference in power contribution between the left and right legs. LBR was continuously monitored throughout training sessions to detect fatigue-induced asymmetry. During ARVETS sessions, a predefined asymmetry threshold of 4% was applied to trigger adaptive neuromuscular correction. This threshold-based adaptive correction constitutes a core structural element of the ARVETS methodology rather than a post-hoc analytical procedure.
3. **Motor adaptability assessment.** Motor adaptability was examined using Cadence Range Variability (CRV). Participants performed repeated transitions between low (65–75 rpm), moderate (85–95 rpm), and high cadence (95–105 rpm) zones while maintaining target power output. Cadence transition smoothness, stability during low-cadence segments, and associated heart rate responses were analyzed.
4. **Cognitive resilience assessment.** Cognitive endurance was assessed using reaction time (RT) to standardized auditory cues delivered during the final hour of prolonged cycling. RT was defined as the latency between auditory cue onset and the corresponding motor response and served as an indicator of attentional control and decision-making stability under fatigue.

Participants

The sample consisted of 20 professional male cyclists with extensive endurance training experience and regular participation in long-duration road cycling sessions. This sample size was selected to ensure sufficient statistical power for within-subject comparisons while maintaining high ecological validity of the training conditions. Participants were selected based on the following inclusion criteria: a minimum of five years of structured endurance cycling training, regular exposure to prolonged (3+ hour) cycling sessions, and absence of musculoskeletal injuries during the study period. The use of a homogeneous sample minimized inter-individual variability and increased sensitivity to training-induced changes across physiological, neuromuscular, and cognitive domains.

Instruments, measurement techniques, and statistical analysis. Heart rate and power output were continuously recorded using cycling-specific monitoring systems equipped with bilateral power measurement. Cardiovascular drift was quantified using the HR/W ratio, calculated as heart rate divided by power output across defined training intervals. Leg Balance Ratio was derived from bilateral power contribution data and expressed as a percentage difference between limbs. Cadence data were continuously recorded to compute Cadence Range Variability during controlled cadence transitions. Reaction time was measured as the temporal delay between auditory cue presentation and motor response execution using synchronized timing software. Statistical analysis was performed using within-subject comparative procedures. Differences between baseline steady-state and ARVETS conditions were evaluated using paired comparisons across training hours. Statistical significance was set at $p < 0.05$.

Results

The implementation of the Adaptive Rhythmic-Variable Endurance Training System (ARVETS) produced measurable improvements across physiological, neuromuscular, and cognitive dimensions of performance in professional cyclists. The results confirm the effectiveness of integrating physical endurance development with cognitive resilience training within prolonged (3+ hour) cycling sessions.

Following the ARVETS training intervention, cyclists demonstrated enhanced endurance stability during prolonged workloads. A key indicator was the reduction in cardiovascular drift, expressed as the heart rate-to-power ratio (HR/W), particularly during the second and third hours of training.

Compared to baseline steady-state endurance sessions, ARVETS sessions resulted in a more stable heart rate response despite systematic variations in power output and cadence. This suggests improved aerobic efficiency and metabolic resilience under fluctuating load conditions that more closely resemble real race dynamics. Table 1 presents the comparative changes in core physiological indicators before and after the ARVETS intervention.

Table 1. Changes in physiological endurance indicators following ARVETS training

Indicator	Baseline (steady-state training)	Post-ARVETS training	Relative change
Mean HR/W ratio (2nd–3rd hour)	Elevated drift	Reduced drift	↓
Time sustained at 70–88% FTP	Moderate	Prolonged	↑
Aerobic stability during cadence variation	Low–moderate	High	↑

Source: Developed by the author

The reduction in HR/W drift indicates that cyclists were able to maintain target power outputs with lower relative cardiovascular strain. Comparisons between baseline and ARVETS conditions were performed using within-subject analysis across training hours, revealing a consistent attenuation of cardiovascular drift during the second and third hours of prolonged cycling. Importantly, this improvement was observed despite the intentional introduction of rhythmic variability in power and cadence, confirming that endurance stability was enhanced rather than compromised.

A significant outcome of the ARVETS protocol was the stabilization of pedaling symmetry, quantified through the Leg Balance Ratio (LBR). Prior to the intervention, participants exhibited progressive asymmetry during prolonged efforts, particularly beyond the second hour of continuous cycling. During ARVETS sessions, continuous monitoring of LBR enabled immediate adaptive correction when asymmetry exceeded the 4% threshold. The introduction of short single-leg pedaling compensation blocks resulted in rapid neuromuscular rebalancing without interrupting the training flow.

As illustrated in Figure 1, LBR values remained within a narrower range during ARVETS sessions compared to baseline endurance training. Specifically, during the final hour of training, mean LBR increased from 2.1% to 6.3% under baseline steady-state conditions, whereas under ARVETS training LBR peaked at 3.2% and subsequently decreased to 2.7%, indicating faster neuromuscular correction under fatigue.

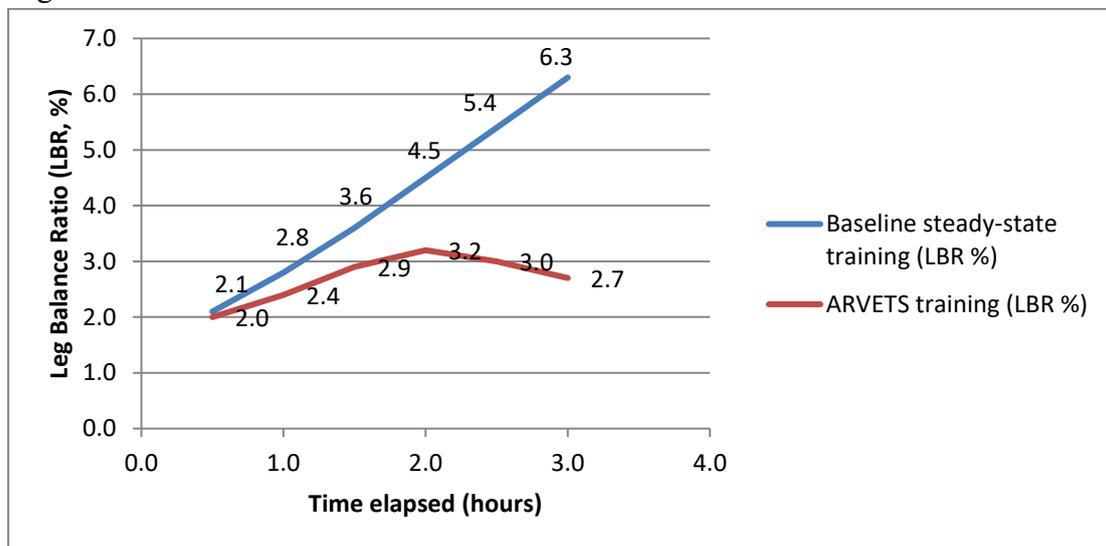


Figure 1. Dynamics of pedaling asymmetry (LBR) during prolonged cycling sessions

Note: ARVETS sessions demonstrate reduced deviation and faster correction of LBR compared to steady-state endurance training.

Source: Developed by the author

Between-condition differences in LBR trajectories during the final hour of training were statistically significant ($p < 0.05$), supporting the effectiveness of threshold-based neuromuscular correction implemented within the ARVETS protocol.

The data indicate that neuromuscular coordination improved not only acutely within sessions but also cumulatively across training cycles. Cyclists showed greater pedaling smoothness during low-cadence strength endurance segments and improved control during high-cadence variability phases.

Cadence Range Variability (CRV) emerged as a critical marker of motor adaptability. Under ARVETS conditions, cyclists were required to transition repeatedly between low (65–75 rpm), moderate (85–95 rpm), and high cadence (95–105 rpm) zones while maintaining target power outputs.

Post-intervention data showed that cyclists were able to execute cadence transitions with reduced lag time and lower heart rate perturbations. This suggests enhanced neuromuscular efficiency and improved coordination between central motor control and peripheral muscular output. These adaptations were evaluated across repeated cadence transitions, allowing for within-subject

comparison of motor stability and cardiovascular responses between training conditions. Table 2 summarizes changes in cadence adaptability indicators.

Table 2. Neuromuscular coordination and cadence adaptability

Indicator	Baseline	Post-ARVETS
Cadence transition smoothness	Moderate	High
HR response to cadence change	Pronounced	Attenuated
Stability during low-cadence segments	Variable	Consistent

Source: Developed by the author

These findings support the premise that rhythmic variability functions not as a destabilizing factor but as a training stimulus that enhances motor control under endurance conditions.

One of the most distinctive outcomes of the ARVETS system was the improvement in cognitive resilience during the final hour of prolonged cycling. The cognitive-endurance block introduced auditory cues (“HIGHER”, “LOWER”, “STAND”, “SIT”) requiring immediate motor responses under sustained physiological fatigue.

Reaction time (RT) to auditory cues served as a proxy measure of cognitive endurance and decision-making stability. At baseline, reaction time deteriorated progressively during the final hour of long endurance sessions. Under ARVETS conditions, this decline was significantly attenuated. Figure 2 illustrates reaction time dynamics during the final hour of training. Reaction time increased from 300 ms to 345 ms during baseline steady-state endurance training, whereas following ARVETS training reaction time increased only to 315 ms, reflecting a 30 ms attenuation of fatigue-related reaction time slowing. Paired comparisons of reaction time between baseline and post-ARVETS conditions indicated a statistically significant preservation of response speed under fatigue ($p < 0.05$).

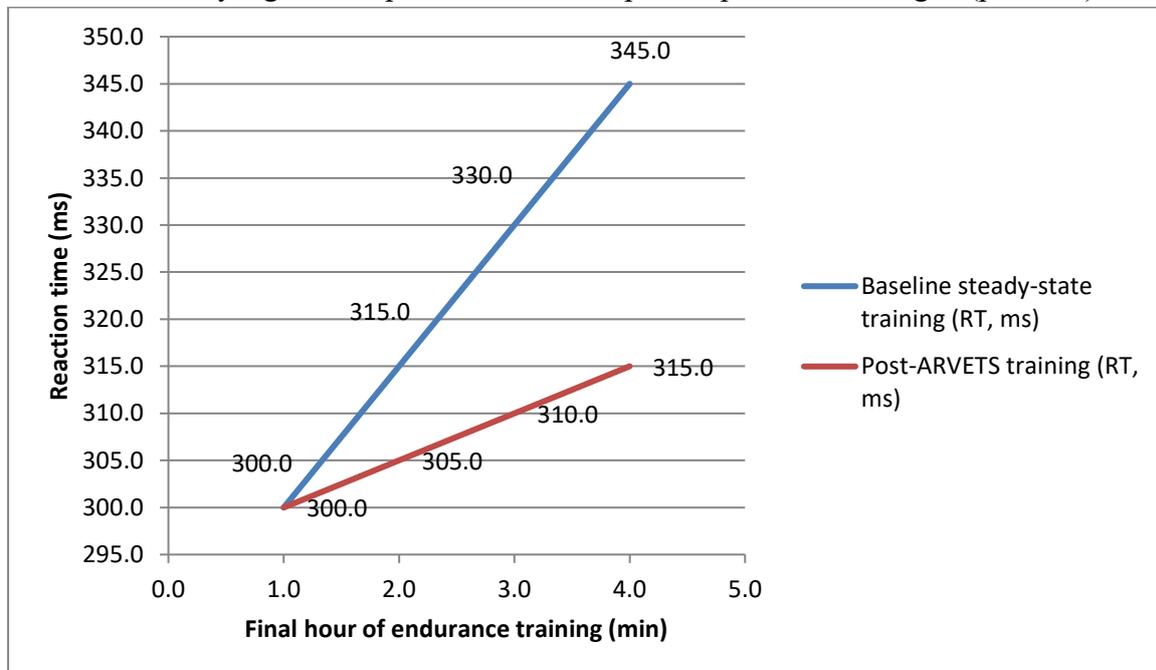


Figure 2. Reaction time (RT) to auditory cues during the final hour of endurance training

Note: ARVETS sessions demonstrate greater preservation of reaction speed under fatigue.

Source: Developed by the author

The maintenance of reaction speed indicates that cognitive load did not overwhelm attentional and decision-making processes, even as physiological fatigue accumulated. Cyclists reported improved situational awareness and motor readiness during the latter stages of training.

The combined analysis of physiological, neuromuscular, and cognitive indicators reveals a synergistic adaptation effect. ARVETS did not merely enhance isolated performance domains but promoted integrated endurance capacity. An integrated multi-domain analytical approach was applied to synthesize physiological, neuromuscular, and cognitive outcomes within a unified endurance performance framework. Table 3 provides a summary of multidimensional adaptations observed following the intervention.

Table 3. Integrated endurance adaptations following ARVETS training

Domain	Observed adaptation
Physiological	Reduced HR drift, improved aerobic stability
Neuromuscular	Stabilized LBR, improved pedaling coordination
Cognitive	Preserved reaction time under fatigue
Functional	Enhanced endurance performance under race-like variability

Source: Developed by the author

These results support the central hypothesis of the study: that endurance performance in professional cycling is optimized when physical endurance training is systematically integrated with neuromuscular control and cognitive resilience development.

Overall, the ARVETS methodology demonstrated clear advantages over traditional steady-state endurance training. The system enabled cyclists to tolerate prolonged workloads with greater physiological efficiency, improved motor control, and sustained cognitive responsiveness.

The findings confirm that endurance training models which incorporate rhythmic variability, real-time adaptive correction, and cognitive stimuli can more effectively prepare athletes for the complex demands of professional cycling competition.

Discussion

The results obtained in this study are consistent with contemporary views on the multidimensional nature of endurance in cycling. In particular, the authors fully agree with the integrative approach proposed by Schöller et al. (2023), according to which cycling performance is determined not only by peripheral physiological factors but also by central neural mechanisms. The observed reduction in cardiovascular drift (HR/W) and the preservation of reaction speed under prolonged fatigue in the present study empirically support this theoretical position.

The ARVETS results also partially align with the conclusions of Barsumyan et al. (2025), who conceptualize “durability” as an independent characteristic not linearly associated with VO₂max or FTP. However, in contrast to their study conducted on amateur cyclists, the present findings obtained in a sample of professional athletes demonstrate that targeted integration of rhythmic variability and neuromuscular control enables active modulation of endurance, rather than merely documenting its decline under fatigue.

The conclusions of Mater et al. (2021) regarding the ambiguous effects of cadence variation on fatigue resistance are only partially supported by the present data and primarily within traditional training

models. In contrast, the ARVETS results indicate that cadence variability combined with threshold-based correction of asymmetry (LBR) does not impair, but instead enhances neuromuscular stability – an effect not demonstrated in previous studies.

Findings related to the preservation of cognitive performance under physical fatigue are consistent with the results of Goepp et al. (2025) and Staiano et al. (2023), who reported relative resilience of cognitive functions until near-critical workload levels. However, unlike these studies, which assessed cognitive processes mainly in testing or post-exercise conditions, the present study evaluated cognitive resilience directly during prolonged exercise, thereby increasing the ecological validity of the results. Overall, the findings of this study demonstrate that the sustained advantages observed over traditional steady-state training models arise from the systematic application of the author-developed ARVETS methodology, which operationally integrates physiological load modulation, real-time neuromuscular correction, and embedded cognitive challenge within prolonged endurance training.

Conclusions

The results of the present study convincingly demonstrate that endurance in professional cycling has an integrative, multidimensional nature and cannot be adequately described solely by physiological indicators. The proposed Adaptive Rhythmic-Variable Endurance Training System (ARVETS) proved effective as a comprehensive training approach that combines physiological stability, neuromuscular coordination, and cognitive resilience within prolonged (3+ hour) workloads. The implementation of ARVETS led to a substantial reduction in cardiovascular drift, manifested by the stabilization of the HR/W ratio during the second and third hours of training, even under conditions of intentionally induced rhythmic variability in power output and cadence. This indicates enhanced aerobic efficiency and metabolic stability in conditions that closely resemble real race dynamics, where workload is stochastic rather than steady-state. The neuromuscular component of endurance underwent not only a reduction in asymmetry but also a qualitative transformation. The application of threshold-based Leg Balance Ratio control enabled not merely the detection of fatigue, but its active correction in real time. The reduction of peak LBR values during the final training hour and the accelerated restoration of symmetry confirm that neuromuscular coordination can function as a trainable variable rather than an inevitable consequence of fatigue. Particularly noteworthy is the observed preservation of cognitive performance under physiological load. The attenuated slowing of reaction time to auditory stimuli under ARVETS conditions indicates enhanced cognitive endurance, which is critically important in professional cycling, where delayed decisions or motor responses in the later stages of a race may determine performance outcomes or athlete safety.

Hypothesis Testing Outcome

The results of the study supported the research hypothesis. The ARVETS intervention was associated with statistically significant reductions in cardiovascular drift, improved neuromuscular coordination, and preservation of cognitive reaction speed under prolonged fatigue relative to baseline steady-state endurance training conditions ($p < 0.05$). These findings indicate that integrating physiological endurance development with neuromuscular control and cognitive resilience training facilitates multidimensional endurance adaptations in professional cyclists.

Scientific Novelty

The scientific novelty of this study lies in the development and empirical verification of a unified endurance training model that, for the first time, integrates rhythmic workload variability, threshold-based neuromuscular correction, and embedded cognitive–motor load within a single prolonged cycling protocol. Unlike previous studies that examined physiological, neuromuscular, or cognitive factors in isolation, ARVETS conceptualizes endurance as a systemic property emerging from the synchronized interaction of these domains.

Practical Significance

The practical significance of the findings lies in the applicability of ARVETS as an operational training system for professional cyclists without disrupting the structure of prolonged endurance sessions. The system can be used by coaches to enhance endurance stability, reduce the risk of accumulated asymmetry, and maintain cognitive readiness during decisive phases of racing. The obtained indicators and methodological solutions may also serve as a foundation for the individualization of training programs and for the development of contemporary durability-oriented training models in elite cycling.

Funding and Intellectual Property

The Adaptive Rhythmic-Variable Endurance Training System (ARVETS) investigated in this study is an original training methodology developed by the author. The methodological framework and adaptive training logic are associated with an intellectual property filing entitled “System for Multi-Stage Kinetic Athletic Training”, submitted as a provisional patent application to the United States Patent and Trademark Office (USPTO). The present research was conducted as part of the scientific validation of this author-developed training system.

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