

Comparative analysis of running power and heart rate responses in elite male orienteers during national and european sprint championships

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Abstract:

Sprint orienteering requires the integration of high-intensity running with continuous technical decision-making, yet little is known about second-by-second mechanical and physiological responses during elite competition. This study compared external (running power) and internal (heart rate) load characteristics of two elite male orienteers across three sprint races: the Bulgarian National Sprint Championships and two European Orienteering Championship events (Sprint Qualification and Knock-Out (KO) Sprint Qualification). Second-by-second running power (Stryd) and heart rate (Suunto chest strap) data were analysed using time-aware segmentation based on official race durations. Variables included mean power, peak 5 s/30 s/60 s power, power variability (CV%), mean heart rate, %HRmax (based on laboratory-verified HRmax), time spent >90% HRmax, pacing indices, HR drift and power–HR decoupling. Mean running power was higher in international competitions for both athletes, particularly in the KO Sprint format, reflecting the influence of shorter race duration and higher mechanical intensity demands. However, physiological responses were athlete-specific: one athlete demonstrated greater cardiovascular strain during European events (~96% HRmax; >95% time >90% HRmax), whereas the other exhibited the highest relative strain during the national competition (~95% HRmax). Differences were also evident in pacing structure, with one athlete showing consistent positive pacing and stable HR responses, while the other demonstrated more variable pacing and greater cardiovascular drift during international races. These findings indicate that sprint orienteering performance is characterised by sustained near-maximal aerobic intensity combined with repeated supramaximal mechanical bursts, whereas physiological load is strongly athlete-specific and not determined by competition level alone. The results support the value of integrated internal–external load monitoring for individualised performance profiling and competition preparation in elite sprint orienteering.

Keywords: sprint orienteering; running power; heart rate response; pacing strategy; performance analytics

Introduction

Orienteering is an endurance sport that combines high-intensity running with complex navigational decision-making performed under time pressure. Unlike traditional road running, performance is determined not only by physiological capacity but also by the athlete's ability to process spatial information, execute optimal route choices and sustain high locomotor intensity. Orienteering performance has also been described as a multidimensional process involving continuous interaction between physical exertion, cognitive processing and rapid decision-making under competitive stress (Yordanov, 2026). Previous work in elite orienteers has also highlighted the importance of psychological and cognitive-related qualities as part of the overall performance model (Sirakov & Belomazheva-Dimitrova, 2021). The physiological demands of competitive orienteering have been shown to involve sustained high heart rate values, often exceeding 85–90% of maximal heart rate during competition (Bird et al., 1993; Bird et al., 2003; Smekal et al., 2003).

Sprint orienteering, typically lasting between 10 and 18 minutes at elite level, represents a particularly demanding format characterised by frequent accelerations, abrupt directional changes and intermittent high-intensity bursts. Gas exchange and lactate measurements during competitive events indicate substantial anaerobic contribution superimposed on high aerobic strain, suggesting that sprint orienteering is not purely steady-state endurance exercise (Smekal et al., 2003; Creagh & Reilly, 1997).

Heart rate (HR) monitoring has long been used as a marker of internal load in endurance sports. HR reflects cardiovascular strain and metabolic demand, and provides practical insight into competition intensity. However, HR responses are influenced by factors such as dehydration, environmental stress and cardiac drift, and may not fully capture rapid changes in mechanical workload during intermittent efforts (Achten & Jeukendrup, 2003; Buchheit, 2014).

Recent advances in wearable technology have enabled the estimation of running power as a metric of external load. Running power aims to quantify the mechanical work rate produced during locomotion and may

provide a more immediate representation of effort compared to pace, particularly in environments where speed is affected by terrain and direction changes. This is particularly relevant in orienteering, where speed fluctuations are frequent and often unrelated to metabolic capacity alone. In addition, running power metrics derived from wearable systems have been shown to provide meaningful insight into endurance performance and metabolic capacity in field settings (García-Pinillos et al., 2021; Imbach et al., 2020; Karparova & Dimitrov, 2024).

The Stryd foot pod is one of the most widely used commercially available running power meters. Validation studies have demonstrated acceptable reliability and repeatability across different running speeds, supporting its application for performance monitoring and comparative load analysis. While absolute validity relative to laboratory-based metabolic measurements remains debated, its sensitivity to intensity changes makes it suitable for within-athlete and between-condition comparisons (Cerezuela-Espejo et al., 2021; García-Pinillos et al., 2021).

From an applied perspective, understanding the interaction between internal and external load during sprint orienteering competition may provide important practical implications for training prescription, pacing optimisation and recovery management. Elite sprint races are characterised by highly stochastic movement patterns, repeated accelerations and rapid fluctuations in exercise intensity that may not be adequately captured using traditional pace-based analysis alone. Integrating running power and heart rate monitoring may therefore offer a more ecologically valid framework for evaluating competition demands and athlete-specific responses in real race environments.

Despite growing interest in running power metrics, research examining their application in orienteering competition is scarce. Recent high-resolution biomechanical analyses in elite sprint orienteering have also demonstrated substantial inter-individual differences in mechanical efficiency, neuromuscular regulation and fatigue-related mechanical drift during competition, further supporting the need for integrated competition-specific monitoring approaches (Sirakov, 2026). At the same time, previous work has emphasised the importance of technical training and performance analysis in the preparation of elite orienteers, underscoring the need for competition-specific monitoring approaches that integrate multiple dimensions of performance (Sirakov & Belomazheva-Dimitrova, 2018). Furthermore, pacing behaviour in endurance sports has been described as a complex, emergent phenomenon influenced by physiological capacity, tactical decisions and competitive context. Higher-level competitions may impose different pacing dynamics due to increased competitive density and tactical pressure (Abbiss & Laursen, 2008; Renfree & Casado, 2018).

International championships typically involve stronger competitive fields and potentially higher technical complexity, which may influence both mechanical load variability and cardiovascular strain. Understanding how elite orienteers respond to differences between national and international competition contexts is relevant for optimising training prescription and competition preparation strategies (Seiler, 2010; Hébert-Losier et al., 2014).

Therefore, the aim of this study was to compare the external (running power) and internal (heart rate) load characteristics of two elite male orienteers during national and international sprint competitions using second-by-second Stryd and heart rate data. In addition, official race performance indicators (race time, placing and time deficit) were integrated to contextualise physiological and mechanical responses relative to competitive outcomes.

Material and Methods

Study Design

This study employed a high-resolution case-study design analysing second-by-second external and internal load responses during three sprint competitions per athlete ($n = 2$ elite male orienteers). Data were collected during the Bulgarian National Sprint Championships (Varna), the European Orienteering Championships – Sprint Qualification (Belgium) and the European Orienteering Championships – Knock-Out Sprint Qualification (Belgium). Only race segments (excluding warm-up and cool-down) were analysed.

External Load Measurement: Stryd Running Power

Running power was measured using the Stryd foot pod (Next Gen version, by Stryd Inc., USA), a wearable inertial measurement device that estimates mechanical power output during running using accelerometry and barometric pressure data.

Stryd has demonstrated high test-retest reliability and strong agreement with laboratory-based metabolic measurements during steady-state running. Although running power estimation is model-based and not a direct mechanical measurement, previous validation studies report high intra-device reliability ($CV < 3\%$), strong correlations with $\dot{V}O_2$ across intensities and stable performance across terrain gradients (Austin et al., 2018; Berzosa et al., 2024; Smith et al., 2022; Pinedo-Jauregi et al., 2022).

Importantly, running power provides a terrain-independent estimate of mechanical output, making it particularly relevant for orienteering, where pace-based metrics are confounded by terrain variability.

Internal Load Measurement: Heart Rate Monitoring

Heart rate was recorded using a Suunto chest strap heart rate monitor (Suunto Oy, Finland), synchronised with the watch system during competition.

Chest strap HR systems have been shown to provide high accuracy compared with electrocardiogram measurements during endurance exercise (Gillinov et al., 2017). HR data were sampled continuously throughout competition and synchronised with running power data.

Maximal heart rate (HR_{max}) was determined through laboratory-based maximal treadmill testing performed to volitional exhaustion prior to the competition period. The verified HR_{max} values were 189 bpm for athlete 1 and 202 bpm for athlete 2. These laboratory-confirmed values were used for relative intensity calculations (%HR_{max} and time >90% HR_{max}).

Data Processing

All data were exported in CSV format and processed using time-aware segmentation procedures:

1. Official race durations were used to isolate the competition segment.
2. Sampling interval was determined using median timestamp differences.
3. Time-based rolling windows (5 s, 30 s and 60 s) were applied to compute peak mechanical power.
4. Data were split into first and second halves based on elapsed time.

Derived metrics included: mean running power (W); peak 5 s, 30 s and 60 s power; power coefficient of variation (CV%); mean HR (bpm); %HR_{max}; time >90% HR_{max} (%); first vs second half mean power and HR; HR drift (%); and power–HR decoupling (% change in HR-to-power ratio).

Second-half power change (Δ Power 2nd Half) was calculated as the percentage difference in mean running power between the first and second halves of each race. Heart rate drift (HR drift) was defined as the percentage change in mean heart rate from the first to the second half. Power–HR decoupling was calculated as the percentage change in the heart rate-to-power ratio between halves, reflecting alterations in internal–external load coupling during competition.

Analytical Approach

The study followed a descriptive performance analytics framework rather than hypothesis testing. Given the small sample size ($n = 2$), emphasis was placed on individual athlete profiling, within-athlete comparisons across competition levels and mechanical-physiological interaction patterns. This approach aligns with contemporary applied sport science models that prioritise individualised performance diagnostics over group-level inference in elite populations (Buchheit & Laursen, 2013). No inferential statistics were performed due to the exploratory case-study design.

Results

Descriptive performance metrics across competitions are summarised in Table I, while time-normalised running power and heart rate profiles are presented in Figure I.

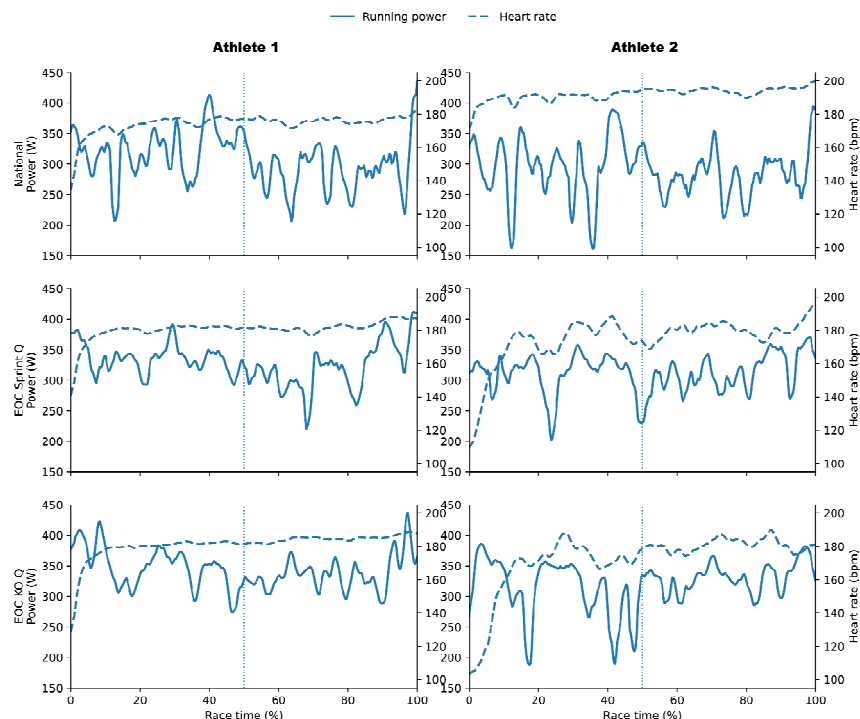


Figure I. Time-normalised running power and heart rate profiles across sprint competitions in two elite male orienteers.

Figure I demonstrates clear between-athlete differences in pacing structure and internal–external load dynamics across competitions.

Mean running power was higher in European Championship races compared with the national sprint competition for both athletes. Athlete 1 demonstrated progressive increases from 306.9 W (Bulgarian Championships) to 328.2 W (EOC Sprint Qualification) and 342.9 W (EOC KO Qualification). Similarly, athlete 2 increased from 289.3 W at the national level to 311.8 W and 320.8 W during the respective European Championship events. The shorter race duration of the KO Sprint format likely contributed to the higher mean mechanical output observed in this event, consistent with established power–duration relationships.

Table I. Mechanical and physiological variables across competitions

Athlete	Competition	Mean Power (W)	Mean HR (bpm)	%HRmax	>90% HRmax (%)	Power CV (%)	HR Drift (%)	Δ Power 2nd Half (%)
Athlete 1	National	306.9	174.6	92.4	89	19.8	2.1	–9.5
Athlete 1	EOC Sprint Q	328.2	180.7	95.6	96	13.0	2.1	–4.6
Athlete 1	EOC KO Q	342.9	181.4	96.0	96	11.4	3.7	–3.2
Athlete 2	National	289.3	192.1	95.1	94	23.6	2.5	–4.3
Athlete 2	EOC Sprint Q	311.8	175.0	86.6	54	13.7	6.3	+1.1
Athlete 2	EOC KO Q	320.8	172.5	85.4	51	16.6	10.1	+6.4

Note: %HRmax calculated using laboratory-determined HRmax (Athlete 1: 189 bpm; athlete 2: 202 bpm).

Δ Power 2nd Half (%) represents percentage change in mean power between halves.

Power variability differed between competition levels. Athlete 1 exhibited reduced coefficient of variation in international races (13.0% and 11.4%) compared to the national competition (19.8%), indicating a more stable mechanical output. Athlete 2 demonstrated the highest variability at the national event (23.6%), with lower values observed internationally (13.7–16.6%).

Internal load responses showed distinct individual patterns. Athlete 1's mean HR increased from 174.6 bpm (92.4% HRmax) at the national level to ~181 bpm (~96% HRmax) in both European Championship races. Time spent above 90% HRmax exceeded 95% of total race duration in international competitions.

In contrast, athlete 2 exhibited the highest physiological strain during the national competition (mean HR 192.1 bpm; ~95% HRmax), with approximately 94% of race time spent above 90% HRmax. International races showed lower mean HR values (172–175 bpm; 85–87% HRmax) and reduced high-intensity exposure (~51–54% of race duration).

First-versus-second-half comparisons revealed consistent positive pacing in athlete 1 (–3 to –9% reduction in mean power), whereas athlete 2 demonstrated a more even-to-progressive pacing pattern in the European competitions (+1 to +6% increase in second-half power). HR drift remained modest in athlete 1 (2–4%) but was more pronounced in athlete 2 during international events (6–10%).

Power–HR decoupling ranged between 7 and 13% in athlete 1 and between 3 and 8% in athlete 2, indicating meaningful alterations in internal–external load coupling during competition.

Discussion

1. Is the international sprint format physiologically more demanding?

The present case analysis demonstrates that competition level does not uniformly determine physiological intensity; rather, responses appear athlete-specific. Importantly, relative intensity values were calculated using laboratory-confirmed maximal heart rate values, strengthening the validity of cardiovascular comparisons across competitions.

For athlete 1, European Championship races elicited higher mean power, higher %HRmax and greater exposure above 90% HRmax compared with the national competition. Both EOC events were performed at ~96% HRmax with >95% of race time spent above 90% HRmax. This indicates an almost fully sustained high-intensity effort, consistent with previous descriptions of elite sprint orienteering as a near-maximal aerobic event with repeated supramaximal surges (Tønnessen et al., 2014).

In contrast, athlete 2 exhibited the highest physiological strain during the national competition (95% HRmax; ~94% time >90% HRmax), while European races were performed at substantially lower relative HR intensities (85–87% HRmax). This suggests that psychological stress, tactical context or pacing choices may modulate internal load independently of mechanical output.

These findings suggest that international competition does not automatically increase physiological intensity; athletes may self-regulate differently depending on tactical context and qualification demands.

2. Mechanical variability and anaerobic bursts

Both athletes showed increased mean power in international competitions, particularly in the KO Sprint format. The KO event, being shorter, allowed higher sustained mechanical output, consistent with the power–duration relationship observed in endurance sports (Jones et al., 2010).

Athlete 1 displayed reduced power variability (CV%) at EOC compared with the national competition, suggesting a more controlled mechanical profile under international conditions. Athlete 2 showed the opposite pattern, with high variability at the national event.

Peak 5-second values (approaching or exceeding 480–500 W in athlete 1) confirm the presence of repeated anaerobic bursts typical of sprint orienteering. These short surges likely correspond to accelerations out of control, direction changes and terrain transitions. The repeated occurrence of short-duration supramaximal efforts suggests a significant anaerobic contribution layered upon a predominantly aerobic performance model.

Sprint orienteering training should include repeated high-power accelerations under fatigue, particularly for athletes competing internationally.

3. Pacing strategies differ between athletes

Athlete 1 demonstrated consistent positive pacing (higher first-half power followed by controlled reduction). HR drift remained low (2–4%), indicating strong aerobic stability and fatigue resistance.

Athlete 2, however, displayed positive pacing at the national level and a more even-to-progressive pacing profile in the EOC races (+1 to +6% second-half power increase), together with greater HR drift internationally (6–10%). This suggests that athlete 2 may have adopted a more conservative opening strategy in European races, possibly to preserve cognitive function for technical sections or due to awareness of qualification thresholds.

Previous research has shown that pacing in high-intensity endurance events is influenced by cognitive load and environmental uncertainty (Abbiss & Laursen, 2008). Orienteering uniquely combines locomotor demand with decision-making under time pressure, which may explain these individualised pacing adaptations.

Coaches should individualise pacing strategy training according to the athlete's pacing profile.

4. Internal–external load coupling and fatigue resistance

Power–HR decoupling provides insight into the relationship between mechanical output and cardiovascular strain. Athlete 1 demonstrated higher decoupling at the national competition (~13%), suggesting greater cardiovascular cost relative to power in the later phase of the race. International races showed lower decoupling (~7%), possibly indicating improved efficiency or more even distribution of effort.

Athlete 2 showed moderate decoupling across competitions, but higher HR drift internationally suggests accumulating cardiovascular strain despite stable or increasing power.

This divergence highlights an important performance principle: athletes can produce similar power outputs while exhibiting markedly different internal strain responses. Similar inter-individual variability has previously been observed in biomechanical regulation patterns during elite sprint orienteering competitions, particularly regarding mechanical variability and fatigue-related adaptations (Sirakov, 2026).

Simultaneous monitoring of running power and heart rate provides a more complete picture of competition load than either metric alone.

Strengths

A key strength of the present case study is the second-by-second integration of mechanical and physiological data across real competitions. This high-resolution approach provides detailed insight into pacing structure, power variability, cardiovascular strain and internal–external load coupling in elite sprint orienteering.

Limitations

Several methodological considerations should be acknowledged when interpreting the present findings.

Firstly, the study included only two athletes, limiting generalisability. However, elite sport performance is inherently individual, and detailed case analyses can provide meaningful applied insight despite small sample sizes.

Secondly, running power measured by the Stryd foot pod represents a model-derived estimate rather than a direct mechanical measurement. Although previous studies have demonstrated acceptable reliability and strong associations with metabolic demand (Austin et al., 2018; Cerezuela-Espejo et al., 2021), absolute power values should be interpreted cautiously. The validity of running power under highly stochastic sprint orienteering conditions (sharp turns, terrain transitions, accelerations) has not been fully established.

Thirdly, heart rate was used as the sole internal load marker. HR is influenced not only by metabolic demand but also by hydration status, environmental conditions, psychological stress and accumulated fatigue (Buchheit, 2014). Thus, HR responses during international competitions may reflect both physiological and psychophysiological stress.

Fourthly, race durations differed between national and international events, particularly in the KO Sprint format. Shorter race duration may partially explain higher mean mechanical intensity due to the power–duration relationship (Jones et al., 2010). While relative intensity metrics were included to mitigate this effect, duration remains a contextual factor.

Finally, GPS and spatial variables were intentionally excluded to isolate physiological-mechanical interactions. However, terrain complexity, route choice decisions and micro-pauses may significantly influence pacing and power variability in sprint orienteering.

Conclusion

This comparative case analysis demonstrated that elite sprint orienteering performance is characterised by sustained near-maximal aerobic intensity combined with repeated supramaximal mechanical bursts. However, physiological intensity was not uniformly higher in international competitions; instead, responses were athlete specific.

Athlete 1 exhibited higher relative cardiovascular strain and mechanical output in European Championship races, suggesting increased international competitive demand. In contrast, athlete 2 demonstrated the highest physiological stress during the national sprint competition, despite lower mechanical output compared with international races. These findings highlight the importance of individualised pacing strategies and the interaction between internal and external load.

Sprint orienteering performance appears to depend not only on absolute mechanical capacity but also on the athlete's ability to regulate effort distribution, maintain mechanical stability and tolerate sustained high-intensity cardiovascular strain. Simultaneous monitoring of running power and heart rate provides valuable insight into performance profiling and individualised competition preparation.

From a broader applied perspective, the present findings reinforce the importance of viewing sprint orienteering as a multidimensional performance task in which physiological intensity, mechanical output and pacing regulation interact continuously under technical and cognitive constraints. The observed athlete-specific responses indicate that competition demands cannot be interpreted solely through absolute intensity metrics, as athletes may achieve similar competitive outcomes through different physiological and pacing strategies. Consequently, integrated monitoring approaches combining running power and heart rate analysis may help coaches identify individual performance profiles, optimise race-specific preparation and improve decision-making regarding pacing, recovery and competition strategy in elite sprint orienteering.

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Conflict of Interest

The author declares no conflict of interest.

Use of Artificial Intelligence Tools

During the preparation of this manuscript, the author used the AI-based tool ChatGPT (OpenAI) exclusively for language refinement, including wording suggestions and clarity improvement. Artificial intelligence was not used for data analysis, statistical calculations, interpretation of results or development of scientific conclusions. All AI-assisted suggestions were critically reviewed and approved by the author, who takes full responsibility for the final content of the manuscript.

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