

Performance-related physiological training-induced modifications and training load distribution of a world champion paracanoe athlete during a season

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Published online: May 31, 2026

Accepted for publication: May 15, 2026

DOI:10.7752/jpes.2026.05103

Abstract

Purpose. There is no evidence on longitudinal performance-physiological adaptations induced by training and training load distribution (TID) in world-class paracanoeist Kayak Level 1 (KL1). This case study examines the KL1 2018 World Champion (WC) and outlines the training program that led to second place in the 2019 WC, providing valuable insights for those aspiring to compete at the same level. To address this gap, the athlete was monitored over 52 weeks through training-data collection and comprehensive physiological assessments. **Methods.** A 34-year-old male paracanoeist underwent testing on three occasions: one week after the 2018 WC, at mid-season, and one week after the 2019 WC. At each time point, he performed an off-water, kayak ergometer cardiopulmonary exercise test (CPET) to assess maximal oxygen uptake ($\dot{V}O_{2max}$), ventilatory thresholds (VTs), and maximal power output (POMax). Additionally, one-repetition maximum (1RM) testing in bench press (BP) and prone bench pull (PBP) was performed at each assessment. Pulmonary function, through a spirometry, was assessed at baseline only. TID during the 52 weeks of trainings was quantified using a three-zone model based on VTs: low-intensity (LIT, $<VT_1$), moderate-intensity (MIT, between VT_1 - VT_2), and high-intensity (HIT, $>VT_2$). The annual training plan included general, specific, competition, and tapering phases organised through sequential macrocycles and weekly microcycles. **Results.** Across the season, $\dot{V}O_{2max}$ showed a modest increase (+6.1% ml/min), while there was a pronounced amelioration of VT_1 (+17% ml/min) and VT_2 (+8.6% ml/min). CPET's POMax (+14.2% W), 1RM in BP (+5.6% kg) and PBP (+7.4% kg) also improved. Overall, he trained 384 hours, comprising 224h of combined on- and off-water kayak training (4.3 ± 0.8 h of weekly kayak training), which followed a non-polarised, hybrid TID approach that combined features of threshold and high-intensity models (LIT: 41%, MIT: 33%, HIT: 26%). **Discussion.** Despite modest changes in $\dot{V}O_{2max}$, substantial improvements at ventilatory thresholds and maximal strength suggest that submaximal efficiency and upper-body neuromuscular capacity may be particularly relevant determinants of KL1 sprint performance. Additionally, the present observations indicate that a hybrid TID with substantial exposure to MIT and HIT, may represent an effective and tolerable approach for optimising race-specific adaptations in world-class paracanoeists. **Conclusion.** Given the anaerobic demands of KL1, paracanoeists appear to require high upper-body strength, an optimised VT_2 , and a threshold-focused TID to excel in international competitions. Although limited to a single athlete, these findings provide a rationale for further investigation in larger KL1 cohorts.

Key Words: ventilatory thresholds, sport periodisation, tapering strategies, spinal cord injury athlete, cardiopulmonary exercise testing,

Introduction

Paracanoe Sprint was officially introduced into the International Canoe Federation World Championships programme at the World Canoe Sprint Championship in 2009 and subsequently included in the Paralympic Games, contributing to the rapid international growth of the discipline. It consists of a flat-water race over a 200m distance in a kayak utilising a double-blade paddle for propulsion. Paracanoeist athletes are classified into three categories: Kayak Level (KL) 1, 2, and 3. This classification ranges from athletes who use both their upper and lower body in paddling (KL3) to athletes who primarily use their upper body due to severe impairments in their legs and trunk (KL1). Consistent with the classification system, performance differs across categories, reflecting the progressive increase in functional capacity from KL1 to KL3 (Ribeiro Neto et al., 2024).

Despite the increasing popularity and competitive development of paracanoe sprint, scientific knowledge regarding the physiological and performance determinants of elite paracanoe athletes is lacking. This represents an important issue for coaches, sport scientists, and practitioners working in high-performance para-

sport environments, as evidence-based training prescription requires a detailed understanding of the physiological characteristics associated with elite performance. In able-bodied canoe and kayak sprint, performance has been shown to depend on a combination of anaerobic power (van Someren & Howatson, 2008), upper-body power (Bielik et al., 2020), and aerobic capacity (Borges et al., 2015; van Someren & Howatson, 2008), emerging as key determinants of competitive success. In this regard, the performance and physiological characteristics of international-level medal-winning canoe and kayak athletes have been thoroughly investigated (Bielik et al., 2020; Crisafulli et al., 2025a; Crisafulli et al., 2025b). Commonly analysed parameters include maximal oxygen consumption ($\dot{V}O_{2\max}$) (Bielik et al., 2020; Crisafulli et al., 2025a; Crisafulli et al., 2025b), ventilatory thresholds (VTs) (Crisafulli et al., 2025b), power output (PO) at which VTs are reached (Crisafulli et al., 2025b), and performance in free-weight exercises (Bielik et al., 2020; Crisafulli et al., 2025a). These informations are used by coaches to assess an athlete's fitness, to design appropriate conditioning programs, and to evaluate the effectiveness of these programs by monitoring the training-induced adaptations.

Moreover, there is a growing interest in documenting and quantifying training volume and training intensity distribution (TID) (Matzka et al., 2021); i.e. defined as the time spent in low- (LIT), medium- (MID), and high-intensity training (HIT) zones (Stöggl & Sperlich, 2014) in international-level athletes. The quantification of TID has become increasingly relevant in endurance, intermittent, and sprint sports, as different distributions of TID may induce specific physiological and performance adaptations. Consequently, several studies have described the training organisation of elite able-bodied athletes in both individual sports, such as canoe sprint (Matzka et al., 2021), triathlon (Cejuela & Sellés-Pérez, 2022), and Nordic combined (Rasdal et al., 2018), and team sports, including Australian football (Moreira et al., 2015) and rink hockey (Fortunati et al., 2025). Similar approaches have also been applied in para-sport contexts, including para-triathlon (Mujika et al., 2015; Quittmann et al., 2022) and paralympic swimming (Baumgart et al., 2021). Collectively, these reports provide practical and evidence-informed insights that may help coaches optimise training prescription and periodisation strategies for athletes aspiring to compete at the highest international level.

However, while these aspects are documented in able-bodied canoe sprint (performance and physiological characteristics (Bielik et al., 2020; Crisafulli et al., 2025a; Crisafulli et al., 2025b), and TID (Matzka et al., 2021)) equivalent evidence in the world of paracanoe sprint is currently lacking. The severe functional limitations characterising KL1 athletes likely influence physiological responses to exercise, training tolerance, force production strategies, and fatigue mechanisms. Therefore, extrapolating training recommendations directly from able-bodied canoe athletes may be inappropriate and potentially misleading. Furthermore, the absence of reference physiological data and training characteristics in elite KL1 paracanoeists limits the ability of coaches and practitioners to establish evidence-informed benchmarks for athlete monitoring and training prescription. Accordingly, further investigations are needed to characterise the physiological profile and training organisation of elite athletes competing in this discipline. Expanding the current level of knowledge may provide valuable practical implications for performance assessment, long-term athlete development, and optimisation of training strategies in Paralympic canoe sprint. Additionally, documenting the training characteristics of world-class paracanoe athletes may help practitioners better understand how elite performance is developed and maintained despite substantial functional impairments. Therefore, the present investigation reports the performance and physiological characteristics of a former World Champion KL1 paracanoeist, together with his training volume, and TID. To address this gap, we longitudinally monitored a world-class KL1 paracanoeist across an entire competitive season, combining physiological-performance testing with detailed training-load and TID quantification. Given the complete lack of data in the KL1 discipline, these findings may provide preliminary, practical, and evidence-informed insights for coaches, sport scientists, and practitioners involved in high-performance paracanoe sprint.

Materials and methods

Participant

The participant was a 34-year-old male paracanoeist. At 25 years of age, he sustained a complete spinal cord injury at the L1 level, secondary to a fall from height, which resulted in paraplegia and permanent wheelchair use. The injury was surgically stabilised with instrumentation spanning T12 to L3. His classification as a KL1 competitor was determined by a multidisciplinary team consisting of a sports physician, a physiotherapist, and three sports technicians from Federazione Italiana Canoa-Kayak and Comitato Italiano Paralimpico throughout a comprehensive evaluation approved by the International Paralympic Committee, encompassing trunk and lower-limb assessments, along with canoe-specific functional tests. From the beginning of his competitive career in 2017 through 2019, he earned two gold medals at the World Championships (WC) (47.116 s, Račice, Czech Republic, 23–27 August 2017; 49.976 s, Montemor-o-Velho, Portugal, 22–26 August 2018) and one silver (46.179 s, Szeged, Hungary, 21–24 August 2019). Over the same period, he also claimed two gold medals (48.520 s, Plovdiv, Bulgaria, 16 July 2017; 47.658 s, Belgrade, Serbia, 8–10 June 2018) and one silver (47.866 s, Poznań, Poland, 21–23 May 2019) at the European Championships. Such results placed him among the highest levels worldwide in the discipline. One week after his victory at the 2018 ICF Paracanoe WC, during the phase of recovery and transition, the paracanoeist and his staff presented to a Sports Medicine Centre

for a cardiopulmonary exercise test (CPET) aimed at assessing his baseline physical condition (termed T0) and providing the basis upon which his coaching team designed the training programme for the subsequent macrocycles, defined as long-term training phases encompassing several microcycles (i.e. weekly program) and structured to achieve specific performance objectives within the annual plan. The evaluation was repeated on two additional occasions, during the second week of the tapering phase of the Specific Preparation (T1) and at the end of the 2019 World Cup (T2). The intermediate evaluation (T1, 24 weeks after the baseline assessment) was designed to assess the effectiveness of the training plan and to refine the prescribed training intensity zones, whereas the final evaluation (T2) aimed to characterise the athlete's overall physiological adaptations. The subject read and signed an informed consent form.

Anthropometric assessment

The body mass of the paracanoeist was measured with a wheelchair platform scale, while his height was measured while lying on the bed. Fat mass percentage, measured with a skinfold calliper (Harpender®, Baly International, UK), was calculated by 8 skinfolds (triceps, subscapular, biceps, iliac crest, supraspinal, abdominal, front thigh, and medial calf) (van Schijndel et al., 2026). Once skinfold thickness was measured at each site, and their sum calculated, body density was estimated using validated predictive equations (Durnin & Womersley, 1974) and subsequently converted to percentage of fat mass (Siri, 1993).

Cardiopulmonary incremental test

The paracanoeist's performance was assessed with an off-water CPET until exhaustion on a calibrated paddle ergometer (Dansprint ApS, Dansprint®, Hvidovre, Denmark). After 5 min of warm-up paddling at an intensity of 60 W, the first stage of the incremental test started at a PO of 75 W with increments of 25 W until exhaustion. Each stage lasted 2 min. The test was considered maximal when it met the following three criteria: blood lactate accumulation (BLA) > 10 mmol/L, respiratory exchange ratio (RER) > 1.1, and $\dot{V}O_2$ at plateau for at least 30s (Crisafulli et al., 2024). HR_{peak} was the maximum HR monitored during the CPET. Blood lactate accumulation (BLA) was measured at exhaustion using the Lactate Pro 2 instrument (Arkay®, Kyoto, Japan) on the athlete's left earlobe (Crisafulli et al., 2024). The maximum value of BLA is referred to as BLA_{peak}. Respiratory gas exchange parameters ($\dot{V}O_2$ consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), and minute ventilation (VE) were continuously recorded using the Cosmed Quark B2 mask (Cosmed®, Roma, Italy). HR was monitored throughout the test by electrocardiogram. Data were analysed using Cosmed® Omnia software. VT₁ was determined using the criteria of an increase in both ventilatory equivalent of oxygen ($\dot{V}E/\dot{V}O_2$) and partial pressure of end-tidal oxygen (PETO₂) with no increase in $\dot{V}E/\dot{V}CO_2$, while VT₂ was identified by an increase in the $\dot{V}E/\dot{V}O_2$ and carbon dioxide ($\dot{V}E/\dot{V}CO_2$) combined with a reduction in the end-expiratory pressure of carbon dioxide (PETCO₂).

Pulmonary function

Pulmonary function was evaluated through a spirometry conducted using the Cosmed Pony spirometer (Cosmed®, Roma, Italy) with the paracanoeist sitting on his wheelchair wearing a nose clip. The test was repeated three times after a self-paced rest period (but not less than 2 minutes) to allow full recovery from acute inspiratory and expiratory muscle fatigue. Direct measurements included FVC (litre), FEV₁ (litre), peak expiratory flow (PEF, litre/minute), and Tiffeneau index (FEV₁/FVC%). The measurements were performed following the European Respiratory Society Technical recommendations (Graham et al., 2019).

Bench Press and Prone Bench Pull

The free-weight bench press (BP) was performed supine on a bench (Technogym®, Cesena, Italy), pressing a barbell from the chest to full elbow extension. The free-weight prone bench pull (PBP) was performed with the chest supported on a bench (Sidea®, Forlì-Cesena, Italy), starting with the elbows fully extended and pulling the barbell until it contacted the underside of the bench, without lifting the chest (Romagnoli et al., 2022). One-repetition maximum (1RM) was assessed starting at ~30% of estimated 1RM, increasing by 10kg to 80%, then 5kg, and finally 2.5–1kg near true 1RM (~95%). The rest between each set was always 4 minutes (Romagnoli et al., 2022). The athlete was highly familiarised with the exercises and the testing protocols. BP and PBP testing were performed at the training facility in accordance with the same temporal cadence adopted for the CPET evaluations.

Control of training loads

HRs, along with POs, were used to establish a triphasic model of TID: Zone 1 or LIT (<VT₁), Zone 2 or MIT (between VT₁ and VT₂), and Zone 3 or HIT (>VT₂) (Skinner & McLellan, 1980). This model was then applied to prescribe training session intensities and used to report all the annual training loads (Matzka et al., 2021; Quittmann et al., 2022).

The paracanoeist recorded all his on-water and off-water paddling sessions with a Garmin® HR chest belt associated with a Garmin® Forerunner 645 sport watch (Garmin®, Olathe, Kansas, USA), as commonly performed in sport science investigations (Fortunati et al., 2023; Mujika et al., 2015). Subsequently, data were transcribed on a customised Excel spreadsheet. The polarisation-index (PI), which is calculated as $\log_{10}(\text{Zone1}/\text{Zone2} * \text{Zone3} * 100)$, was calculated in every microcycle to identify the type of TID (Matzka et al., 2021). Specifically, if PI > 2.00 a.u., the TID is defined as polarised, with increasing values indicating a higher level of polarisation. If PI ≤ 2.00 a.u., the TID is defined as non-polarised (Treff et al., 2019).

Main Characteristics of the Training Period

Following the 2018 World Championships, the paracanoeist completed a 3-week transition and recovery period. The subsequent preparation toward the next major international competition in Szeged consisted of 49 consecutive 7-day microcycles, organised into four sequential training phases (Phases 1–4). The phases were not of equal duration and were structured as follows: Phase 1, General Preparation (GP, 10 weeks); Phase 2, Specific Preparation (SP, 10 weeks); and Phases 3 and 4, corresponding to Competition Phase 1 (CO1, 17 weeks) and Competition Phase 2 (CO2, 12 weeks), respectively (Issurin, 2010).

Results

Physiological and performance training-induced adaptations

Across the observation period (T0–T2), the paracanoeist exhibited progressive adaptations in body composition (reduced fat mass), physiological responses (higher $\dot{V}O_{2\max}$ and marked upward shifts in both $\dot{V}T_1$ and $\dot{V}T_2$, and performance outcomes (higher $PO_{\max}$ and 1RMs) (Table 1).

Table 1. Performance-physiological training-induced adaptations in a KL1 World Champion

Variables	Time of assessment		
	T0	T1 (%#)	T2 (%*)
<i>Anthropometric and body composition</i>			
Body mass (kg)	81.0	82.1 (+1.3%)	82.0 (+1.2%)
Lean body mass (kg)	65.3	66.1 (+1.2%)	66.4 (+1.7%)
Lean body mass (%)	80.6	80.5 (-0.1%)	81.0 (+0.5%)
Body fat (kg)	15.7	16.0 (+1.9%)	15.6 (-0.6%)
Body fat (%)	19.4	19.5 (+0.5%)	19.0 (-2.1%)
<i>Pulmonary function</i>			
FVC (l)	4.62	-	-
FEV1 (l)	4.08	-	-
PEF (l/sec)	13.02	-	-
FEV1/FVC% (%)	89	-	-
<i>Physiological characteristics</i>			
$\dot{V}O_{2\max}$ (ml/min)	3396	3528 (+3.9%)	3605 (+6.1%)
$\dot{V}O_{2\max}$ (ml/min/kg)	41.9	43.0 (+2.6%)	43.9 (+4.7%)
$\dot{V}O_2\dot{V}T_1$ (ml/min)	2595	2850 (+9.8%)	3037 (+17.0%)
$\dot{V}O_2\dot{V}T_1$ (% $\dot{V}O_{2\max}$)	76.4	80.7 (+5.6%)	84.2 (+10.2%)
$\dot{V}O_2\dot{V}T_2$ (ml/min)	3036	3220 (+6.1%)	3297 (+8.6%)
$\dot{V}O_2\dot{V}T_2$ (% $\dot{V}O_{2\max}$)	89.3	91.2 (+2.1%)	91.4 (+2.3%)
HRpeak (bpm/min)	190	190 (+0%)	190 (+0%)
HRVT ₁ (bpm/min)	170	167 (-1.8%)	165 (-2.9%)
HRVT ₁ (%HRmax)	89.4	88.3 (-1.2%)	86.8 (-2.9%)
HRVT ₂ (bpm/min)	182	180 (-1.1%)	177 (-2.7%)
HRVT ₂ (%HRmax)	95.7	94.7 (-1.0%)	93.1 (-2.7%)
BLapeak (mmol/l)	14.2	15.4 (+8.4%)	14.9 (+4.9%)
<i>Performance</i>			
$PO_{\max}$ (W)	175	200 (+14.3%)	200 (+14.3%)
$POVT_1$ (W)	125	150 (+20.0%)	150 (+20.0%)
$POVT_1$ (% $W_{\max}$)	71.4	75 (+5.0%)	75 (+5.0%)
$POVT_2$ (W)	150	175 (+16.7%)	175 (+16.7%)
$POVT_2$ (% $W_{\max}$)	86	87.5 (+1.7%)	87.5 (+1.7%)
1RM Bench press (kg)	125	130 (+4.0%)	132 (+5.6%)
1RM prone bench pull (kg)	135	140 (+3.7%)	145 (+7.4%)

1RM one-repetition maximum; bpm/min beats per minutes; BLamax blood lactate maximum; FEV1 forced expiratory volume capacity in the first second; FEV1/FVC% Tiffeneau index; FVC forced volume capacity; HR heart rate; HRmax heart rate maximum; kg kilograms, l litre; l/sec litre/second; ml/min millilitre/minute; ml/min/kg millilitre/minute/kilogram; mmol/L millimole/litre; PEF peak expiratory flow; $PO_{\max}$ power output; $PO_{\max}$ maximum power output; T0 baseline assessment; T1 intermediate assessment; T2 final assessment; $\dot{V}O_{2\max}$ maximal volume of oxygen consumed; $\dot{V}T_1$ first ventilatory threshold; $\dot{V}T_2$ second ventilatory threshold; % percentage; W watt; $W_{\max}$ watt maximum. # Relative change T1-T0; * Relative change T2-T0

Main Characteristics of the Training Period

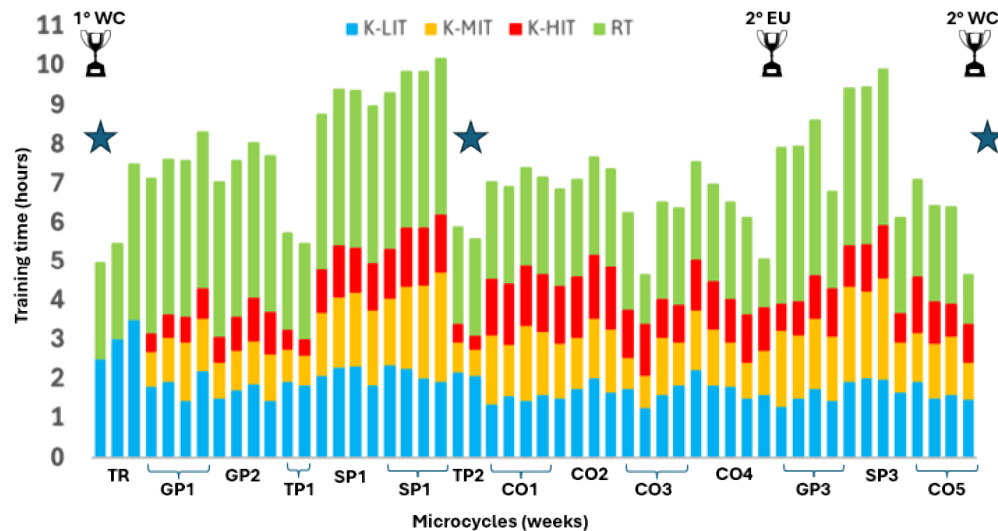
The main characteristics of the training season, including macrocycle duration, weekly paddle training volume, TID, and PI, are reported in Table 2, with a graphical overview provided in Figure 1. The transition phases were characterised by exclusive LIT, whereas the GP, SP, and CO phases exhibited a progressive redistribution of training time across all three intensity zones, showing a non-polarised TID.

Table 2. Macrocycle's on- and off-water kayak training volume and training intensity distribution

Phases	Description	Duration	Paddle training time								PI
		Weeks	Hours	Zone 1 - LIT		Zone 2 - MIT		Zone 3 - HIT			
				min	%	min	%	min	%		
1	Transition Phase	3	9.0	540	100	0	0	0	0	n/a	
	General Preparation 1	4	14.7	443	50	289	33	150	17	1,41	
	General Preparation 2	4	14.5	392	45	251	29	224	26	1,61	
	Taper Phase 1	2	6,3	225	65	95	28	25	7	2,26	
2	Specific Preparation 1	4	20.6	511	41	429	35	294	24	1,45	
	Specific Preparation 2	4	23.3	513	37	535	38	350	25	1,38	
	Taper Phase 2	2	6,5	255	65	85	22	52	13	2,26	
3	Competition 1	4	18.6	357	32	393	35	364	33	1,47	
	Competition 2	4	19.1	416	36	346	30	384	34	1,61	
	Competition 3	4	15.2	386	42	250	28	273	30	1,67	
	Competition 4	5	21.1	538	42	365	29	363	29	1,63	
4	General Preparation 3	4	16.9	360	36	415	41	236	23	1,31	
	Specific Preparation 3	4	20.5	455	37	507	41	268	22	1,29	
	Competition 5	4	15.9	389	41	303	32	263	28	1,55	

min minutes, % percentage, *PI* polarization index, *LIT* low-intensity training, *MIT* medium-intensity training, *HIT* high-intensity training.

Figure 1. Fifty-two-week training time distribution between resistance training and kayak training, further subdivided into low-, medium-, and high-intensity kayak training sessions.



TR transition phase, *GP* general preparation phase (1 to 3), *TP* taper phase 1 and 2, *SP* specific preparation phase (1 to 3), *CO* competition phase (1 to 5), *K-LIT* kayak low-intensity training, *K-MIT* kayak medium-intensity training, *K-HIT* kayak high-intensity training, *RT* resistance training. OF note, each column represents one week of training. Colours legend: *light blue* K-LIT; *orange* K-MIT, *red* K-HIT, *green* RT

★ represents the week in which the paracanoeist underwent performance evaluations (CPET and 1RM testing)
 represents participation in international competition.

Discussion

This study aimed to detail, for the first time, the performance and physiological training-induced adaptations, along with the training regimen of a KL1 World Champion. Briefly, this investigation documents overall favourable changes in body composition (lean body mass and fat mass), physiological characteristics ($\dot{V}O_{2\max}$, occurrence of VTs), along with performance indicators (POs and 1RMs) during an entire season. Regarding the training period, its main characteristics are a non-polarised TID, with a great proportion of time spent at MIT and HIT.

Performance and physiological training-induced adaptations

Despite stable body mass, which is also reported in a select cohort of world-class kayakers during two seasons (García-Pallarés et al., 2010), small increases in lean body mass was observed from T0 to T2. Notably,

the body fat percentage observed in the present paracanoeist is consistent with values reported in cohorts of wheelchair para-athletes competing in aerobic or intermittent team sport (Flueck, 2020; Goosey-Tolfrey et al., 2021; van Schijndel et al., 2026). Furthermore, the use of the sum of eight skinfolds to estimate body fat percentage has been shown to be strongly associated with dual-energy X-ray absorptiometry measurements in similar para-athlete populations (Goosey-Tolfrey et al., 2021; van Schijndel et al., 2026), supporting the validity of the present assessment.

Baseline pulmonary function values were comparable to those reported in an able-bodied cohort of younger kayakers (Mazic et al., 2015), and with values corresponding to 88.1%, 94.8%, 132.9%, and 110.8% of the predicted values for FVC, FEV1, PEF, and FEV1/FVC, respectively, indicating preserved ventilatory function and no evidence of ventilatory limitation (Stanojevic et al., 2022). Given the low neurological level of injury, the absence of respiratory symptoms, and that pulmonary function is unlikely to be a limiting factor for performance in sprint paddle sports, it was not reassessed at subsequent time points.

The progressive increase in $\dot{V}O_{2\max}$ observed from T0 to T2, although small to moderate in magnitude, is physiologically meaningful given the paracanoeist's already highly trained status at baseline. This is confirmed by the fact that in elite athletes, world-class kayakers comprised, large improvements in $\dot{V}O_{2\max}$ are limited even with structured training (García-Pallarés et al., 2010; Legaz Arrese et al., 2005; Midgley et al., 2006), as performance gains are more closely linked to improvements in submaximal thresholds or efficiency (Midgley et al., 2006). Indeed, in the present paracanoeist, the most relevant adaptations were observed at submaximal intensities. At his peak physical condition, the paracanoeist showed a $\dot{V}O_{2\max}$ inferior to that of able-bodied kayakers (≈ 57 -68 ml/min/kg (Bielik et al., 2020; Borges et al., 2015; Michael et al., 2008; Zouhal et al., 2012)), which is possibly due to the reduced amount of functional muscle mass (and thus oxidative capacity) that can be recruited by the subject (Theisen, 2012). Indeed, a situation of paralysis leads to the slow-to-fast twitch fiber-type shifts, along with a reduced number and function of mitochondria (Gorgey et al., 2019; Talmadge et al., 2002), maladaptations that may explain the reduced $\dot{V}O_{2\max}$. Surprisingly, the occurrence of VT_2 as % $\dot{V}O_{2\max}$ is aligned with those of a selected cohort of younger top-level flat-water male kayak paddlers (García-Pallarés, Carrasco, et al., 2009) and superior to those of international-level medallists winning kayakers (Crisafulli et al., 2025b). These results suggest that, despite lower $\dot{V}O_{2\max}$, the paracanoeist exhibits comparable anaerobic and ventilatory adaptations to able-bodied peers. This physiological conditioning may have supported his successful performance in the anaerobic demands of KL1.

Performance-related outcomes improved clearly from baseline, with $PO_{\max}$ during CPET comparable to values reported in cohorts of international-level medal-winning kayakers (Crisafulli et al., 2025b), which would indicate excellent training-induced adaptations. Regarding upper-body strength, the marked increases in 1RMs observed in both the BP and PBP would suggest the effectiveness of the RT programme implemented. The magnitude of improvement in BP and PBP reported in this research is consistent with the gains obtained after 8-12 weeks of structured concurred training combining RT and kayak practice in male world-class, flat-water paddlers (García-Pallarés, Sánchez-Medina, et al., 2009). Moreover, the absolute 1RM values achieved in both BP and PBP are comparable to those reported in senior international-level kayakers (Romagnoli et al., 2022) and exceed those documented in younger competitive kayakers (Crisafulli et al., 2025a). Collectively, these findings highlight the paracanoeist's exceptional upper-body strength, which, given the demands of KL1 racing, is likely to represent a key contributor to competitive performance. Indeed, maximal strength in both BP and PBP has been identified as a significant predictor of kayak sprint performance (Kristiansen et al., 2023; Romagnoli et al., 2022).

Main Characteristics of the Training Period

The paracanoeist did not experience any training interruptions during the season. Over the course of the 52-week period, he completed a total of 384 training hours, comprising 224h of combined on- and off-water kayak training and 160h of RT. Specifically, the paracanoeist performed 4.3 ± 0.8 h of kayak training per week. This volume is slightly lower than that performed by younger, able-bodied regional- and national-level kayakers (Matzka et al., 2021). This difference may be explained by the greater proportion of LIT prescribed in that cohort, likely reflecting their lower competitive level and training age. Indeed, athletes at this stage may derive greater benefit from long-term athletic development-oriented models, which emphasise higher volumes of LIT to build aerobic capacity and technical proficiency. Regarding TID, after 3 weeks of LIT to facilitate the physical and mental regeneration of the paracanoeist after the WC competition, he performed the subsequent annual plan of 49 microcycles, averaging 41% (107 ± 17 min) in Zone 1/LIT, 33% (87 ± 30 min) in Zone 2/MIT, and 26% (67 ± 21 min) in Zone 3/HIT. This distribution reflects a hybrid approach, combining features of a "threshold TID", which emphasises training at moderate intensity (e.g., 40-50-10%), and a "high-intensity TID", characterised by a greater reliance on high-intensity work (e.g., 20-10-70% or 43-0-57%) (Treff et al., 2019). This anaerobic-oriented TID appears consistent with the energy demands of KL1 competition and may have favourable effects on tolerance to short-duration, high-intensity exercise. A similar periodisation approach, but with reduced LIT and a contemporaneous increased in MIT and HIT (24-29% LIT, 26-38% MIT, 33-47% HIT) has been successfully prescribed to ten male, younger, top-class elite flatwater kayak paddlers (García-Pallarés et al., 2010), suggesting the effectiveness and tolerability of this training regimen. Collectively, it seems that for

KL1 events, the observed hybrid, anaerobic-oriented TID may be particularly effective in enhancing the paracanoeist's capacity to sustain maximal effort over the race duration, while balancing sufficient LIT to support recovery and technical proficiency.

Across the macrocycles, when considered in isolation, only the two TPs exhibited a polarised TID (PI >2.0 a.U.). This pattern resulted from the inclusion of very short bouts of HIT interspersed with long recovery intervals performed at LIT. TP1, implemented after GP2, was characterised by a modest reduction in kayak training volume (−13% and −20% across the two microcycles), consistent with a linear tapering strategy (Bosquet et al., 2007). In contrast, TP2, implemented after SP2, showed a markedly larger reduction in training volume (−45% and −50%; from approximately 6 h 10 min to 3 h 24 min and 3 h 6 min, respectively), reflecting an exponential taper with a fast decay constant, in line with current recommendations (Bosquet et al., 2007). The different tapering strategies likely reflect the preceding training context: during GP2, weekly training volume was still in a progressive build-up phase, whereas SP2 culminated in some of the highest training loads of the season. Notably, despite differences in total volume reduction, both tapering phases were characterised by a substantial decrease in HIT exposure (approximately 55–65%) consistent with the use of very short, high-intensity bouts to preserve neuromuscular performance while minimising residual fatigue (Mujika et al., 2004).

Conclusion

This case study provides the first longitudinal description of the seasonal training organisation, physiological and performance adaptations, and TID of a world-class KL1 paracanoe athlete.

Over the 52-week period, he successfully completed uninterrupted training and maintained international-level performance. Overall, he trained 384 hours, comprising 224h of combined on- and off-water kayak training (4.3±0.8h of weekly kayak training) and 160h of RT. The training process was characterised by a hybrid TID approach that combined features of threshold and high-intensity models, with approximately 41% of the weekly kayak training performed at LIT, 33% at MIT, and 26% at HIT. This distribution differed from the predominantly low-intensity approaches commonly described in endurance sports and appeared more consistent with the anaerobic and upper-body dominant demands of KL1 sprint events.

From a physiological and performance perspective, the most meaningful adaptations were observed at submaximal intensities, with marked improvements in both VT_1 (from 2595 to 3037 ml/min, +17.0%) and VT_2 (from 3036 to 3297 ml/min, +8.6%), accompanied by increases in PO_{max} (from 175 to 200 W, +14.3%) and upper-body strength (1 RM BP, from 125 to 132 kg, +5.6%; 1RM in PBP, from 135 to 145 kg, +7.4%). In contrast, $\dot{V}O_{2max}$ showed only modest changes (from 3396 to 3605 ml/min, +6.1%), supporting the concept that, in highly trained KL1 athletes, performance development may depend more on improvements in threshold-related efficiency, anaerobic tolerance, and neuromuscular function than on $\dot{V}O_{2max}$ alone. Additionally, the athlete demonstrated exceptionally high levels of upper-body maximal strength, reinforcing the importance of RT in KL1 preparation.

From a practical standpoint, these findings may help coaches and sport scientists better understand the physiological demands and training characteristics associated with successful KL1 performance. In particular, the present observations suggest that a hybrid TID with substantial exposure to MIT and HIT, combined with structured RT, may represent an effective and tolerable approach for optimising race-specific adaptations in world-class paracanoeists. Furthermore, the tapering strategies adopted before major competitions highlight the importance of reducing overall training volume while maintaining brief high-intensity stimuli to preserve neuromuscular readiness and minimise accumulated fatigue.

Although limited to a single athlete and therefore not generalisable to all KL1 paracanoeists, this work provides preliminary evidence and a rationale for future investigations in larger cohorts. Future studies should examine whether similar TID models and physiological-performance adaptations are consistently associated with elite-level performance across different paracanoe classifications.

Statements and Declarations

Declaration of generative AI and AI-assisted technologies in the writing process. The authors declare that no artificial intelligence (AI) tools were used in the writing, analysis, or preparation of this manuscript.

Author Contributions: Conceptualisation: M.F., T.G., O.C., and G.D. Data collection: M.F., T.G., and L.G. Drafting of the manuscript: M.F. and O.C. Critical revision: O.C. and G.D. All authors have read and agreed to the published version of the manuscript.

Ethical considerations. Not applicable.

Consent to participate. Informed consent was obtained from the subject involved in the study.

Consent for publication. The participant provided written informed consent for the publication of this case report.

Declaration of conflicting interest. The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding statement. The authors disclosed receipt of financial support for the research, authorship, and/or publication of this article.

Data Availability Statement. The data associated with the paper are not publicly available but are available from the corresponding author on reasonable request.

Acknowledgments. The authors would like to acknowledge Dr. Maria Douvli Smith for her professional English editing of the manuscript.

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