

On-Water Prescribed Training Intensity Distribution and Ability-Related Training Composition in Elite Junior Male Canoe Sprint Athletes Preparing for the 2025 ICF Junior Canoe Sprint World Championships: An Observational Case Study

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Abstract

This longitudinal observational case study characterized the phase-specific organization of on-water training volume, prescribed training intensity distribution (TID), and ability-related training composition in an elite junior male canoe sprint squad preparing for the 2025 ICF Junior Canoe Sprint World Championships. A common squad-level prescribed on-water training programme followed by six athletes was monitored across a 35-week preparation macrocycle, with weeks 1–34 included in the main analysis and week 35 designated as post-championship recovery. On-water training volume was quantified using effective paddling duration. Prescribed R1–R6 training components were summarized into Z1 (R1), Z2 (R2), and Z3 (R3–R6), while training purpose was independently classified as aerobic-oriented, mixed aerobic–anaerobic, acid-tolerance, or speed-oriented. Mean weekly on-water training volume was 325, 266, 247, and 210 min·week⁻¹ in P1, P2, CP1, and CP2, respectively. Overall prescribed TID followed a pyramidal pattern (Z1: 58.08%, Z2: 24.17%, Z3: 17.75%), which was also maintained across phases despite phase-specific variation. Ability-related training composition was predominantly aerobic-oriented (83.55%), followed by mixed aerobic–anaerobic (11.09%), speed-oriented (3.46%), and acid-tolerance training (1.89%). These findings describe the prescribed on-water training organization of this specific elite junior canoe sprint squad and should not be interpreted as evidence of the effectiveness or optimality of the observed training structure.

1 Introduction

Canoe sprint is a cyclic sport characterized by substantial aerobic and anaerobic demands, together with the ability to generate and sustain high power output during competition. Accordingly, training requires the systematic organization of sport-specific volume and intensity across different phases of preparation. Understanding how these training components are organized over an extended preparation period is particularly relevant for elite junior athletes preparing for major international competitions.

Training intensity distribution (TID) describes the relative proportion of training allocated across different intensity levels within a defined training period and is an important component of endurance training organization^[1–3]. Three commonly described TID patterns are the pyramidal (PYR), polarized (POL), and threshold (THR) models. PYR is characterized by the greatest proportion of training at low intensity, followed by progressively smaller proportions at moderate and high intensities. POL also emphasizes low-intensity training but includes a greater proportion of high- than moderate-intensity training, whereas THR involves a relatively greater proportion of moderate-intensity training. These patterns have been widely examined in endurance sports, including rowing, cycling, and cross-country skiing^[4–6]. Their application may vary according to sport-specific demands, athlete characteristics, competition schedules, and training objectives.

In canoe sprint, training organization must address the combined demands of aerobic endurance, high-intensity exercise, power production, and technical execution. Previous studies have examined sport-specific ability development, periodized training design, and training volume in canoe sprint athletes^{[7–}

^{10]}. However, longitudinal evidence describing how on-water training volume and prescribed TID are organized across a complete preparation macrocycle remains limited, particularly in elite junior canoe sprint athletes. Moreover, intensity-based classification describes one dimension of training organization but does not necessarily reflect the primary purpose of the prescribed training content. Training intensity and training purpose therefore represent related but distinct dimensions of training organization, and their combined examination may provide a more complete description of applied training practices.

Accordingly, the present observational case study analyzed longitudinal on-water training data from elite junior male canoe sprint athletes of the Chinese National Junior Canoe Team during a 35-week preparation macrocycle for the 2025 ICF Junior Canoe Sprint World Championships. The study aimed to characterize phase-related changes in on-water training volume and prescribed TID, while independently examining ability-related training composition according to the primary purpose of the prescribed training content. This approach provides a descriptive account of the phase-specific organization of on-water training in this elite junior male canoe sprint squad.

2 Methods

Experimental approach to the problem

This study adopted an observational case study design, consistent with previous season-long training monitoring research on elite endurance athletes ^[11]. Annual on-water training monitoring data were collected from elite junior canoe athletes of the Chinese National Junior Canoe Team during their preparation for the 2025 ICF Junior Canoe Sprint World Championships. No additional training interventions were implemented in this study, and all training sessions were arranged by the coaching staff in accordance with the annual training plan and routine monitoring procedures.

The monitored 35-week preparation macrocycle was structured based on the team's annual preparation plan and the fundamental principles of periodized training ^[12–13]. The overall preparation period was subdivided into Preparation Phase 1 (P1; weeks 1–12) and Preparation Phase 2 (P2; weeks 13–22), whereas the competition period was divided into Competition Phase 1 (CP1; weeks 23–31) and Competition Phase 2 (CP2; weeks 32–34). Week 35 was designated as the post-championship recovery period, which was only included to demonstrate the complete macrocycle structure and excluded from the main phase comparisons regarding TID and ability-related training composition.

P1, Preparation Phase 1; P2, Preparation Phase 2; CP1, Competition Phase 1; CP2, Competition Phase 2. Week 35 was defined as the recovery period after the World Championships and was excluded from the main phase comparisons of TID or ability-related training composition.

Participants

Six elite junior male canoe sprint athletes from the Chinese National Junior Canoe Team were included in the present analysis. The athletes had a mean age of 18.5 ± 0.3 years, a mean height of 178.2 ± 3.5

cm, a mean body mass of 77.3 ± 2.1 kg, and 4.18 ± 0.6 years of systematic training experience. All athletes were eligible for and competed in the Junior category at the 2025 ICF Junior Canoe Sprint World Championships. Participant characteristics are presented in Table 1. All six athletes competed in the finals of their respective single-canoe or double-canoe events. One athlete won a gold medal, two won silver medals, and the remaining three finished outside the top three. Competition results are reported only to characterize the competitive level of the athletes and were not used as an analytical outcome. Written informed consent was obtained from all participants, and the study was approved by the Ethics Committee of Wuhan Sports University (Approval code: 2024257).

Table 1
Characteristics of included and excluded athletes

Variable	Mean $\pm$ SD
Age(years)	18.5 ± 0.3
Height(cm)	178.2 ± 3.5
Body mass(kg)	77.3 ± 2.1
Training experience(years)	4.18 ± 0.6

Training monitoring procedures

On-water training data were recorded throughout the preparation macrocycle. Training intensity was prescribed according to the R1–R6 framework routinely used by the Chinese National Junior Canoe Team. The training content and target intensity of each session were determined by the coaching staff according to the squad’s training status, phase-specific training objectives, competition schedule, and routine monitoring information. Before each session, all athletes were informed of the prescribed training content and target intensity. Similar approaches combining prescribed training intensity with routine physiological and performance monitoring have been used in canoe sprint and kayak training research^[14–16].

Stroke rate and heart rate were routinely monitored during on-water training using a SpeedCoach GPS 2 system (Nielsen-Kellerman Co., USA) and a Polar H9 heart rate monitor (Polar Electro Oy, Finland), respectively. Blood lactate concentration was additionally measured during selected testing sessions, controlled training sessions, and trial races using a Lactate Plus portable lactate analyzer and test strips (Nova Biomedical, USA). Stroke rate, heart rate, and blood lactate are commonly used as complementary indicators for monitoring training intensity and physiological response in canoe sprint and related paddling disciplines^[14–15]. In the present study, these variables served as complementary monitoring indicators for evaluating the execution of the prescribed training rather than as individualized physiological thresholds for defining the R1–R6 categories.

Each recorded on-water training component was assigned a priori to an R1–R6 category according to the training content and target intensity prescribed by the coaching staff before the session. Heart rate, stroke rate, and blood lactate responses were used to support the evaluation of training execution and were not used to retrospectively reclassify training components. This distinction between prescribed intensity and observed physiological or performance responses is important in sprint kayaking because different monitoring metrics may produce different estimates of time spent within prescribed intensity zones, particularly during high-intensity training ^[17–18]. Accordingly, when observed responses did not correspond exactly with the reference ranges of the prescribed category, the component remained assigned to its originally prescribed R1–R6 category.

Data structure and aggregation

The six athletes followed the same squad-level on-water training programme prescribed by the coaching staff throughout the analyzed preparation period. Accordingly, the analytical unit of the present study was the common squad-level prescribed training programme rather than six independent athlete-level training programmes. The reported session counts, prescribed training-category occurrences, and effective paddling durations therefore represent programme-level values and were not obtained by summing or averaging six separate athlete-level training records. A total of 165 on-water training sessions were included in the analysis across weeks 1–34, comprising 65 sessions in P1, 51 in P2, 39 in CP1, and 10 in CP2. An on-water training session was defined as one complete on-water training occasion. Within a single session, the prescribed training content could include more than one separately recorded component assigned to an R1–R6 category. When a session contained multiple prescribed training components, the session was not assigned to a single session-level intensity category; instead, each component was recorded separately according to its prescribed R1–R6 category. Across the analyzed period, 444 prescribed training-category occurrences were recorded, comprising 131 in P1, 146 in P2, 131 in CP1, and 36 in CP2. Each occurrence corresponded to one separately recorded prescribed training component and was treated independently from the session count. Component-level effective paddling durations were subsequently aggregated to obtain weekly, phase-specific, and overall training-volume values.

Table 2
Summary of on-water training records across the analytical phases

Phase	Weeks	On-water sessions(n)	Prescribed training-category occurrences (n)	Effective paddling duration (min)	Mean weekly volume (min·week ⁻¹)
P1	1–12	65	131	3900.5	325
P2	13–22	51	146	2659	266
CP1	23–31	39	131	2219	247
CP2	32–34	10	36	629.5	210
Overall	1–34	165	444	9408	277

Values represent the common squad-level prescribed on-water training programme. A prescribed training-category occurrence refers to one separately recorded training component assigned to an R1–R6 category, and a single on-water training session could contain more than one occurrence. Phase-specific mean weekly volume was calculated by dividing the effective paddling duration of each phase by the number of weeks in that phase. The overall mean weekly volume was calculated by dividing the total effective paddling duration (9,408.0 min) by the 34 analyzed weeks. Exact mean weekly training-volume values are reported in Table 2, whereas rounded whole-minute values are used in the text and Fig. 2 for ease of presentation.

Training volume

On-water training volume was quantified using effective paddling duration (min), defined as the net duration of active paddling. Recovery intervals and other non-paddling periods were excluded. The effective paddling duration associated with each recorded training component was accumulated within each session and subsequently aggregated to obtain weekly, phase-specific, and overall on-water training volume.

For each analyzed week, total on-water training volume was calculated as the sum of the effective paddling durations accumulated across the six prescribed R1–R6 categories (Total = R1 + R2 + R3 + R4 + R5 + R6). Phase-specific training volume was obtained by summing the corresponding weekly values within each phase. Mean weekly training volume was calculated by dividing the accumulated training volume by the number of analyzed weeks within the corresponding phase. The overall mean weekly training volume was calculated using the same procedure across weeks 1–34.

Training intensity distribution and ability-related training composition

TID was calculated using a three-zone model, which has been widely adopted in research on endurance sports and canoe sprint training [1, 14, 19]. In the present study, TID represents the distribution of coach-prescribed on-water training intensity rather than physiological time-in-zone derived from individualized physiological thresholds. During routine training practice, the prescribed training intensity for each session was determined by the coaching staff according to the squad's training status, phase-specific training objectives, competition schedule, and routine monitoring information. Before each training session, all athletes were informed of the prescribed training content and target intensity. On-water training was recorded using the R1–R6 intensity framework routinely adopted by the Chinese National Junior Canoe Team. The stroke-rate, heart-rate, and blood-lactate values associated with each category served as practical reference ranges for routine training monitoring rather than individualized physiological thresholds or mandatory cut-off values. Accordingly, gaps or overlaps between the listed reference ranges did not determine category assignment.

Previous sprint-kayak studies have used individualized physiological or performance-based measures to quantify athlete-specific training intensity and have shown that estimates of time spent within intensity zones may vary according to the monitoring variable used [18, 20]. In contrast, the R1–R6 framework used

in the present study represented the practical prescribed-intensity system routinely applied by the coaching staff and was not intended to represent individualized physiological training zones.

For the present TID analysis, R1 was classified as Zone 1 (Z1; low intensity), R2 as Zone 2 (Z2; moderate intensity), and R3–R6 as Zone 3 (Z3; high intensity). R3–R6 were grouped into Z3 because these categories represented the higher-intensity portion of the team’s prescribed R1–R6 framework. This aggregation was applied only for the three-zone TID summary and does not imply physiological equivalence among R3–R6. The original R1–R6 categories were retained and reported separately to preserve information on the different forms of higher-intensity training. Stroke rate, heart rate, and blood lactate concentration were used as complementary monitoring indicators to provide information on the execution of the prescribed training ^[21](Table 3).

Table 3

Practical R1–R6 prescribed on-water intensity framework and mapping to the three-zone TID model

Prescribed category	TID zone	Training intensity	Reference stroke rate (strokes·min ⁻¹)	Reference heart rate (beats·min ⁻¹)	Reference blood lactate (mmol·L ⁻¹)
R1	Z1	LIT	< 30	120–140	< 3
R2	Z2	MIT	30–40	150–160	4–6
R3	Z3	HIT	40–50	180–190	8–10
R4	Z3	HIT	50–60	> 190	10–14
R5	Z3	HIT	60–70	Maximal	10–15
R6	Z3	HIT	> 70	Maximal	< 12

The R1–R6 framework represents the team-specific prescribed-intensity system routinely used by the coaching staff of the Chinese National Junior Canoe Team. Stroke-rate, heart-rate, and blood-lactate values are practical reference ranges derived from established team training practice and were used to support routine monitoring of training execution. These values were not individualized physiological thresholds or mutually exclusive criteria for assigning R1–R6 categories. LIT, low-intensity training; MIT, moderate-intensity training; HIT, high-intensity training.

TID was quantified based on the accumulated effective paddling duration within each intensity zone rather than total session duration or a session-goal method. When a training session contained more than one prescribed R1–R6 training component, the effective paddling duration associated with each component was recorded separately and allocated to its corresponding R1–R6 category. These durations were subsequently aggregated into Z1, Z2, and Z3 for the three-zone TID analysis. Recovery intervals and other non-paddling periods were excluded. The proportion of each TID zone was calculated by dividing the accumulated effective paddling duration within that zone by the total effective on-water

paddling duration for the corresponding period. TID was calculated for the entire preparation macrocycle and separately for P1, P2, CP1, and CP2.

Training-category occurrence frequency was quantified according to the number of separately recorded prescribed R1–R6 training components. Each recorded on-water training component assigned to an R1–R6 category was counted as one occurrence. Because a single on-water training session could contain more than one prescribed training component, training-category occurrence frequency was not equivalent to session frequency. Across the 165 analyzed on-water training sessions, 444 prescribed training-category occurrences were recorded. The relative occurrence frequency of each R1–R6 category was calculated by dividing the number of occurrences assigned to that category by the total number of prescribed training-category occurrences and multiplying by 100.

Training-category occurrence frequency(%)=
$$\frac{\text{Number of prescribed occurrences assigned to a given R1--R6 category}}{\text{Total number of prescribed training-category occurrences}} \times 100$$

In addition to the intensity-based R1–R6 classification, the same on-water training components were classified according to the primary ability targeted by the prescribed training content. Ability-related categories were assigned prospectively by the coaching staff before training, based on the primary prescribed purpose and specific content of each training component. Each recorded on-water training component was assigned to one of four categories: aerobic-oriented, mixed aerobic–anaerobic, acid-tolerance, or speed-oriented training. When a training component involved more than one potential training objective, classification was based on the primary purpose specified in the prescribed training plan. The ability-related classification was therefore part of the routine pre-training prescription rather than a retrospective classification performed by the researchers. No separate post hoc second-rater verification was conducted. This classification represented a separate dimension of the training records from the R1–R6 intensity framework and was not derived from fixed combinations of R1–R6 categories. The classification criteria for the four ability-related categories are presented in Table 4.

Table 4
Ability-related classification of on-water training content

Ability-related category	Classification basis
Aerobic-oriented	Training primarily prescribed to develop aerobic endurance and sustained paddling capacity
Mixed aerobic–anaerobic	Training primarily prescribed to develop sustained high-intensity output involving substantial aerobic and anaerobic contribution
Acid-tolerance	Training primarily prescribed to improve tolerance to high metabolic stress during repeated or sustained high-intensity efforts
Speed-oriented	Training primarily prescribed to develop speed endurance, maximal speed, or short-duration high-power output

Ability-related categories reflected the primary prescribed training purpose assigned prospectively by the coaching staff before training. When a training component involved multiple potential objectives, classification was based on its primary prescribed purpose. This classification was separate from the R1–R6 intensity framework and was not derived from fixed combinations of R1–R6 categories.

Ability-related training composition was quantified using effective paddling duration. The effective paddling duration of each recorded on-water training component was allocated to its corresponding ability-related category, and the accumulated duration of each category was calculated for the relevant analysis period. The proportion of each ability-related category was determined by dividing its accumulated effective paddling duration by the total effective on-water paddling duration within the same period and multiplying by 100. This calculation was performed for the entire preparation macrocycle and separately for P1, P2, CP1, and CP2. Accordingly, ability-related training composition was quantified independently from the R1–R6-based prescribed TID and should not be interpreted as the direct sum of specific R1–R6 categories.

$$\text{Ability-related training composition(\%)} = \frac{\text{Accumulated effective paddling duration assigned to the category}}{\text{Total effective on-water paddling duration}} \times 100$$

Statistical analyses

All training data were organized and summarized using Microsoft Excel 2024. Descriptive analyses were performed for the entire preparation macrocycle and separately for P1, P2, CP1, and CP2. On-water training volume was expressed as effective paddling duration (min), and the distributions of R1–R6, TID, and ability-related training composition were expressed as percentages of the corresponding total on-water training duration. Continuous variables are presented as mean $\pm$ standard deviation where applicable. Phase-related differences were examined descriptively, and no inferential statistical tests were performed.

3 Results

Phase-related changes in on-water training volume

On-water training volume varied across the 34 analyzed weeks of the 35-week preparation macrocycle (Fig. 2). Mean weekly on-water training volume was 325 min·week⁻¹ in P1, 266 min·week⁻¹ in P2, 247 min·week⁻¹ in CP1, and 210 min·week⁻¹ in CP2, with an overall mean of 277 min·week⁻¹ across the analyzed period. Training volume was generally higher during the preparation phases and lower during the competition phases.

Across the prescribed R1–R6 categories, R1 accounted for the largest proportion of total effective paddling duration and remained the predominant training category across the macrocycle, followed by R2. Week 3 was a competition week in which all recorded on-water training was prescribed as R1. Week 7 was also a competition week and was characterized predominantly by R1 training, with 306 min prescribed as R1 and 17 min as R3. No R2 or R4–R6 training components were recorded during Week 7.

R3–R6 generally accounted for smaller proportions of training volume and were concentrated in selected training weeks. Overall, R1 and R2 constituted the major components of on-water training volume, whereas R3–R6 were prescribed in smaller and more variable amounts across the preparation macrocycle.

Total weekly on-water training volume represents the sum of effective paddling duration accumulated across R1–R6. Week 3 was a competition week in which all recorded on-water training was prescribed as R1, whereas Week 7 consisted predominantly of R1 training (306 min) with a small amount of R3 training (17 min). Dashed horizontal lines indicate mean weekly training volume within each analytical phase.

Distribution of training volume and training-category occurrence frequency across R1–R6 categories

The distribution of training volume and training-category occurrence frequency across the R1–R6 categories is presented in Fig. 3. R1 accounted for the largest proportion of total on-water training volume (58.08%) and training-category occurrence frequency (44.82%). R2 accounted for 24.17% of total on-water training volume and 17.57% of training-category occurrence frequency, while the corresponding proportions for R3 were 10.92% and 15.99%, respectively. R4–R6 accounted for relatively small proportions of total training volume. Specifically, R4, R5, and R6 represented 1.87%, 2.13%, and 2.83% of total training volume, respectively, with a combined proportion of 6.83%. In contrast, their combined training-category occurrence frequency was 21.62%, indicating that these categories were recorded relatively frequently despite accounting for a small proportion of total effective paddling duration.

Prescribed training intensity distribution across the preparation macrocycle and phases

The overall prescribed on-water TID followed a pyramidal pattern across the analyzed preparation macrocycle, with Z1 accounting for the largest proportion of total training volume (58.08%), followed by Z2 (24.17%) and Z3 (17.75%) (Fig. 4). A pyramidal distribution ($Z1 > Z2 > Z3$) was also observed in each of the four analytical phases, although the relative contribution of each zone varied across phases.

During P1 and P2, Z1 accounted for 61.75% and 59.95% of training volume, respectively, while Z2 represented 25.61% and 21.36% and Z3 represented 12.64% and 18.69%. The distribution changed more markedly in CP1, with Z1 decreasing to 45.07%, accompanied by increases in Z2 (27.94%) and Z3 (26.99%). In CP2, Z1 increased to 73.39%, whereas Z2 and Z3 decreased to 13.82% and 12.79%, respectively. Thus, although the relative distribution of the three intensity zones varied across phases, the overall pyramidal structure was maintained throughout the preparation macrocycle.

Weekly TID also showed considerable variation across the macrocycle (Fig. 5), particularly in the relative contributions of Z1, Z2, and Z3 during individual training weeks. Despite these week-to-week fluctuations, the accumulated TID across the entire macrocycle remained characterized by a predominance of Z1, followed by Z2 and Z3.

Ability-related training composition across phases

Using the independent ability-related classification, aerobic-oriented training accounted for the largest proportion of total effective on-water paddling duration across the preparation macrocycle (83.55%; Fig. 6). Mixed aerobic–anaerobic training accounted for 11.09%, while acid-tolerance and speed-oriented training accounted for 1.89% and 3.46%, respectively.

Aerobic-oriented training remained the predominant component across all four phases, accounting for 77.74%–87.36% of on-water training volume. The proportion of mixed aerobic–anaerobic training increased from 9.01% in P1 to 11.44% in P2 and 15.79% in CP1, before decreasing to 6.99% in CP2.

Acid-tolerance training remained relatively limited across phases, ranging from 0.08% to 2.59% of on-water training volume. Speed-oriented training also accounted for a relatively small proportion overall, reaching 5.17% in P2 and 5.72% in CP2. Overall, the ability-related training composition was characterized by a predominance of aerobic-oriented training, with descriptive phase-related variation in mixed aerobic–anaerobic, acid-tolerance, and speed-oriented training.

4 Discussion

The present case study examined on-water training volume, prescribed training intensity distribution (TID), and ability-related training composition in Chinese elite junior canoe athletes during the preparation period for the 2025 ICF Junior Canoe Sprint World Championships. The main findings indicated that on-water training volume exhibited distinct phase-related changes, with higher and more variable weekly volume during the preparation phases and lower, more concentrated volume during the competition phases. The overall prescribed TID followed a pyramidal pattern, with Z1 accounting for the largest proportion of total effective paddling duration, followed by Z2 and Z3. This prescribed intensity structure was retained across all four analytical phases, although the relative contribution of each zone varied across phases. These results describe the organization of coach-prescribed on-water training intensity rather than athlete-specific physiological time-in-zone. Ability-related training composition was predominantly aerobic-oriented, whereas mixed aerobic–anaerobic, acid-tolerance, and speed-oriented training constituted smaller proportions.

The phase-related reduction in on-water training volume from the preparation to competition phases aligns with the general principles of periodized training. Periodization theory emphasizes that training volume and content are adjusted according to annual training plans, competition schedules, and phase-specific objectives. Preparation phases typically involve greater accumulation of training volume, whereas competition phases are characterized by progressive load regulation as major competitions approach^[22]. Similar phase-related adjustments in training volume and intensity distribution have been reported in elite endurance athletes^[23]. In canoe sprint athletes, changes in training volume and content have also been reported across different phases of a periodized training cycle^[24]. Accordingly, the lower on-water training volume observed during the competition phases in the present study may reflect a planned reduction in accumulated training volume and a redistribution of training content in accordance with competition-specific training objectives.

The overall TID observed in this study exhibited a pyramidal pattern. This finding aligns with the existing literature on endurance training, which indicates that both well-trained and elite endurance athletes typically complete a large proportion of their training at low intensities ^[19, 25]. Although pyramidal, polarized, and threshold TID models have been implemented in endurance sports, their application depends on the demands of the sport, the athlete's level, the training phase, and the targeted adaptations ^[19, 26]. Intervention and comparative studies have previously shown that polarized training yields positive adaptations in trained cyclists and recreational runners ^[2, 27]. Similarly, other research has demonstrated that both pyramidal and combined TID approaches can support the development of endurance performance ^[28–29]. Additional studies indicate that the efficacy of polarized and threshold-based models may vary based on the athlete population and the specific training context ^[30–31]. Consequently, the pyramidal pattern observed in the present study should not be interpreted as universally superior or optimal; rather, it represents the prescribed training-intensity structure adopted by this specific elite junior canoe sprint squad during the monitored preparation macrocycle.

The predominance of Z1 training may reflect the substantial volume of aerobic-oriented work incorporated into the preparation of junior canoe sprint athletes. Canoe sprint performance requires high power output while also involving considerable sport-specific training volume, technical execution, and fatigue management. Previous studies have identified several factors associated with sprint canoe and kayak performance, including aerobic power, anaerobic capacity, upper-body and paddling-specific power output, and technical efficiency ^[21, 32–35]. More broadly, maximal oxygen uptake, lactate threshold, and exercise economy have been recognized as important physiological determinants of endurance performance ^[33]. These findings provide context for the combined aerobic and high-power demands of canoe sprinting. In the present study, however, these physiological and performance-related factors were not directly assessed; therefore, the predominance of Z1 training should be interpreted as a characteristic of the observed training organization rather than evidence of specific physiological adaptations or performance benefits.

A notable finding of this study was that the pyramidal TID pattern was maintained across all main training phases. No clear shift from one TID model to another was observed. In adult or training-mature endurance athletes, TID may exhibit more pronounced phase-related changes in response to competition demands, tapering strategies, or targeted performance adaptations ^[23, 36]. For example, elite rowers may adjust training intensity and load according to their preparation status and heart rate variability ^[36], while world-class distance runners often structure their training around a large low-intensity base, with selective increases in race-specific training content approaching competition ^[37]. Compared with these adult and more mature athlete populations, the junior canoe athletes in the present study demonstrated a more stable intensity structure, indicating that phase regulation was achieved primarily through proportional adjustments within the pyramidal model rather than through distinct model transitions.

The relatively stable prescribed TID observed across phases should be interpreted within the broader context of training organization in young endurance athletes. Previous research in young world-class

rowers has shown that a large proportion of training volume is accumulated at low intensity, with training organization considered in relation to long-term athlete development^[38]. The progression from junior to senior peak performance in world-class cross-country skiers has also been associated with gradual changes in training organization and session design^[39]. Endurance training in young athletes should therefore be considered in the context of physical growth, biological maturation, and long-term athletic development^[40]. However, the present study did not assess biological maturation or include a senior-athlete comparison group. Therefore, the relatively stable pyramidal pattern observed in this squad cannot be attributed specifically to the developmental characteristics of junior athletes and should instead be interpreted as a descriptive feature of the prescribed training organization adopted during the monitored preparation macrocycle.

Phase-related variation in prescribed TID was evident within the overall pyramidal structure. Z2 increased in CP1 relative to the preceding phases, accompanied by a reduction in Z1, whereas both Z2 and Z3 subsequently decreased in CP2 as the proportion of Z1 increased. These changes indicate that the relative contribution of the prescribed intensity zones was adjusted across phases while the overall pyramidal pattern was retained. Such phase-related variation is consistent with the view that TID may be organized flexibly according to phase-specific training objectives rather than maintained as a fixed distribution throughout a preparation cycle ^[23, 25]. However, because the present study did not assess physiological adaptations, fatigue responses, or performance changes associated with these adjustments, their specific functional effects cannot be determined.

The composition of ability-related training further supports this interpretation. Aerobic-oriented training accounted for the largest proportion of total on-water training volume, indicating that the preparation macrocycle was primarily structured around aerobic-oriented training. This does not indicate that canoe sprint performance is determined solely by aerobic capacity; rather, it shows that aerobic-oriented training constituted the predominant component of the prescribed on-water training programme for this squad. Mixed aerobic–anaerobic training exhibited clear phase-related variation, increasing from P1 to CP1 before declining in CP2. This pattern may reflect a phase-specific transition from foundational training toward more competition-specific demands. In particular, the higher proportion of mixed aerobic–anaerobic training in CP1 may reflect greater emphasis on sustained power output, race-pace regulation, and competition-specific training demands, whereas the subsequent reduction in CP2 may reflect a decrease in accumulated training stress as the main competition approached.

Acid-tolerance training and speed-oriented training accounted for relatively small proportions of total on-water training volume. These training contents were distributed selectively across the preparation macrocycle rather than constituting major components of the overall prescribed on-water training programme. Their limited contribution may reflect the coaching staff's phase-specific organization of higher-intensity training content within the broader training process. However, because physiological and performance adaptations were not directly assessed, the present study cannot determine the physiological effects or performance benefits associated with these training contents.

The interpretation of training intensity in sprint kayak and canoe should also consider differences between prescribed training intensity and physiological or performance-based measures of training intensity. Previous sprint-kayak research has shown that estimates of training intensity may vary depending on the monitoring method used and that heart rate and stroke rate may not fully represent the demands of short-duration supramaximal training when compared with power-based quantification [17–18]. In the present study, stroke rate, heart rate, and blood lactate concentration were used as complementary indicators to monitor the execution of prescribed training rather than as individualized criteria for retrospectively assigning R1–R6 categories. Accordingly, the prescribed TID reported in this study represents the distribution of coach-prescribed on-water training intensity and should not be interpreted as athlete-specific physiological time-in-zone.

From an applied perspective, the present findings provide a descriptive example of how prescribed on-water training was organized across a major competition-preparation macrocycle in an elite junior canoe sprint squad. The data show that a pyramidal prescribed TID was maintained while the relative contributions of the prescribed intensity zones and ability-related training categories varied across phases. These observations may assist coaches and practitioners in comparing training organization across similar applied settings; however, they should not be interpreted as evidence that the observed training structure is optimal, developmentally appropriate, or superior to alternative training-intensity distributions.

5 Limitations

Several limitations should be considered when interpreting the present findings. First, this observational case study involved a small group of elite junior male canoe sprint athletes from a single national team; therefore, the findings primarily describe the training organization of this specific squad and may not be directly generalizable to other athlete populations or training environments. Second, the study was based on routine training monitoring rather than a controlled experimental design, and causal relationships between training organization and subsequent adaptations cannot be established. Third, the R1–R6 framework represented the practical prescribed-intensity classification routinely used by the coaching staff and was not derived from individualized physiological thresholds. Heart rate, stroke rate, and blood lactate concentration were used as complementary monitoring indicators rather than criteria for defining individualized physiological zones. Accordingly, the reported TID reflects coach-prescribed on-water training intensity and may not correspond directly to athlete-specific physiological time-in-zone. Fourth, the TID analysis was restricted to on-water training and did not include dryland strength or non-specific endurance training. Fifth, ability-related training categories were assigned prospectively according to the primary prescribed purpose of each training component, and no independent second-rater verification or inter-rater reliability assessment was conducted. Finally, no longitudinal physiological or sport-specific performance outcomes were assessed, and no inferential statistical analyses were performed. Accordingly, the study describes the observed training organization but cannot determine its effectiveness, optimality, or causal contribution to competition performance.

6 Conclusion

This longitudinal observational case study characterized the phase-specific organization of prescribed on-water training in an elite junior male canoe sprint squad preparing for the 2025 ICF Junior Canoe Sprint World Championships. On-water training volume was higher during the preparation phases and lower during the competition phases. The overall prescribed TID followed a pyramidal pattern, with Z1 accounting for the largest proportion of training volume, followed by Z2 and Z3, while the relative contribution of each zone varied across phases. Ability-related training composition was predominantly aerobic-oriented, with phase-specific variation in mixed aerobic–anaerobic, acid-tolerance, and speed-oriented training. These findings provide a descriptive account of the training organization adopted by this specific squad and should not be interpreted as evidence of the effectiveness or optimality of the observed training structure.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the ethical principles of the World Medical Association's Declaration of Helsinki. Written informed consent was obtained from all participants, and all study procedures were approved by the ethics committee of Wuhan Sports University (Approval code: 2024257, Date: 20 September 2024).

Consent for publication

Not Applicable.

Availability of data and materials

The aggregated data supporting the findings of this study are presented within the article. De-identified programme-level data necessary to reproduce the reported summary statistics and figures are available from the corresponding author upon reasonable request, subject to approval by the Chinese National Junior Canoe Team and the relevant institutional authorities. Detailed operational training records are not publicly available because they contain confidential information relating to the team's preparation programme.

Competing interests

The authors declare no competing interests.

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Author contributions

Q.S. drafted the manuscript. Y.Y. revised the manuscript and provided conceptual guidance for the study. J.C. assisted with software use and data processing. J.X., J.W., S.L., X.W., Y.L., C.D., and T.Z. contributed to data collection, organization, and manuscript preparation. All authors have read and approved the final version of the manuscript.

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Not applicable.

Clinical trial number

Not applicable.

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Figures

World Junior Championships preparation macrocycle																																						
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35			
Phase	Preparation Phase 1												Preparation Phase 2										Competition Phase 1										Competition Phase 2					Recovery phase
Period	Preparation Phase												Competition Phase																									
Training focus	Development of sport-specific ability and technical refinement												Sport-specific enhancement and race-intensity adaptation																							Recovery		

Figure 1. Overview of the 35-week preparation macrocycle of the Chinese National Junior Canoe Team

P1, Preparation Phase 1; P2, Preparation Phase 2; CP1, Competition Phase 1; CP2, Competition Phase 2. Week 35 was defined as the recovery period after the World Championships and was excluded from the main phase comparisons of TID or ability-related training composition.

Figure 1

See image above for figure legend.

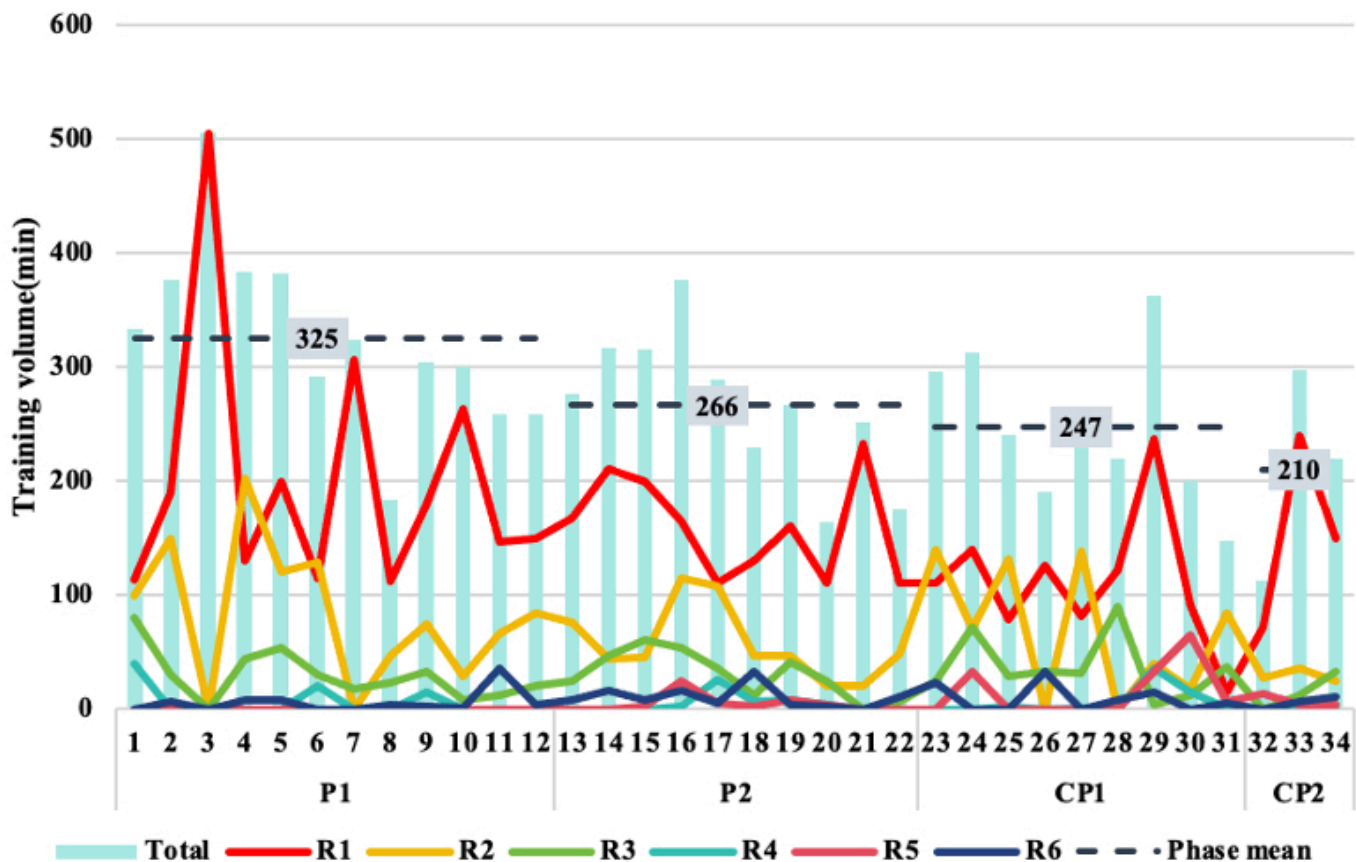


Figure 2. Weekly on-water training volume across prescribed R1–R6 training categories and phase mean values

Total weekly on-water training volume represents the sum of effective paddling duration accumulated across R1–R6. Week 3 was a competition week in which all recorded on-water training was prescribed as R1, whereas Week 7 consisted predominantly of R1 training (306 min) with a small amount of R3 training (17 min). Dashed horizontal lines indicate mean weekly training volume within each analytical phase.

Figure 2

See image above for figure legend.



Figure 3. Distribution of training volume and training-category occurrence frequency across R1–R6 prescribed training categories.

Figure 3

See image above for figure legend.

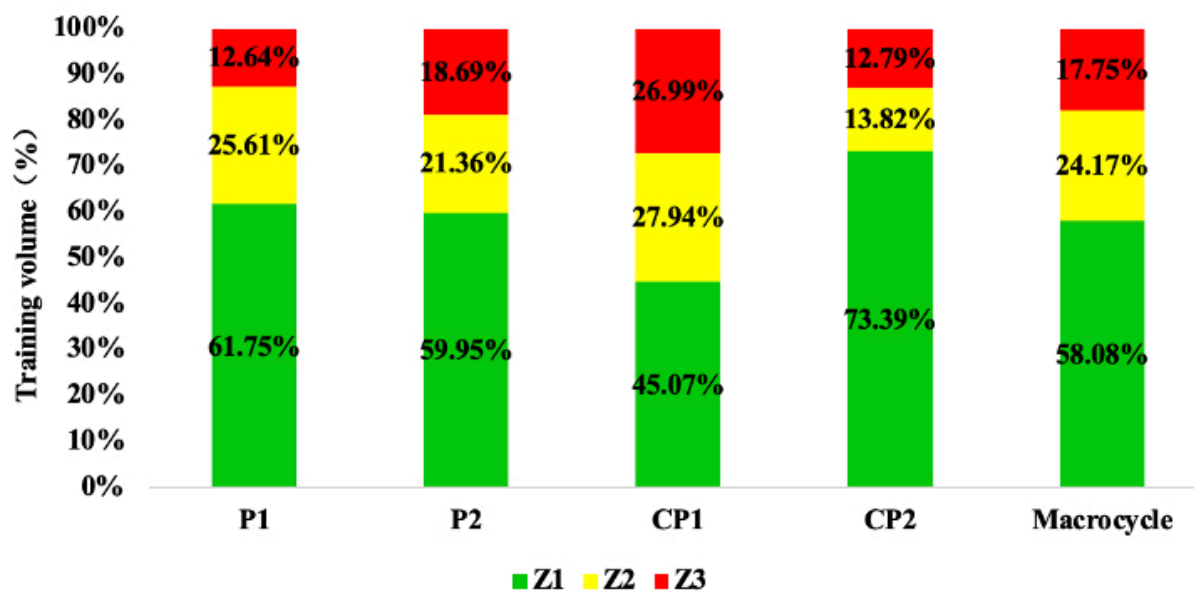


Figure 4. Prescribed on-water TID across training phases

Figure 4

See image above for figure legend.

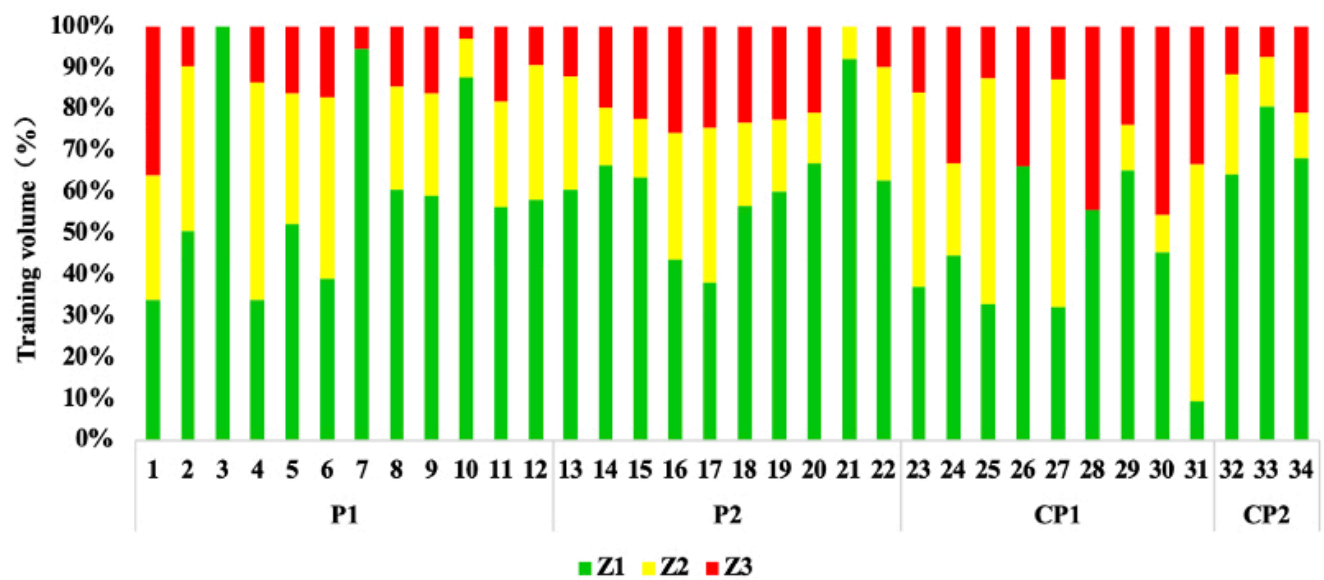


Figure 5. Weekly prescribed on-water TID across the preparation macrocycle

Figure 5

See image above for figure legend.

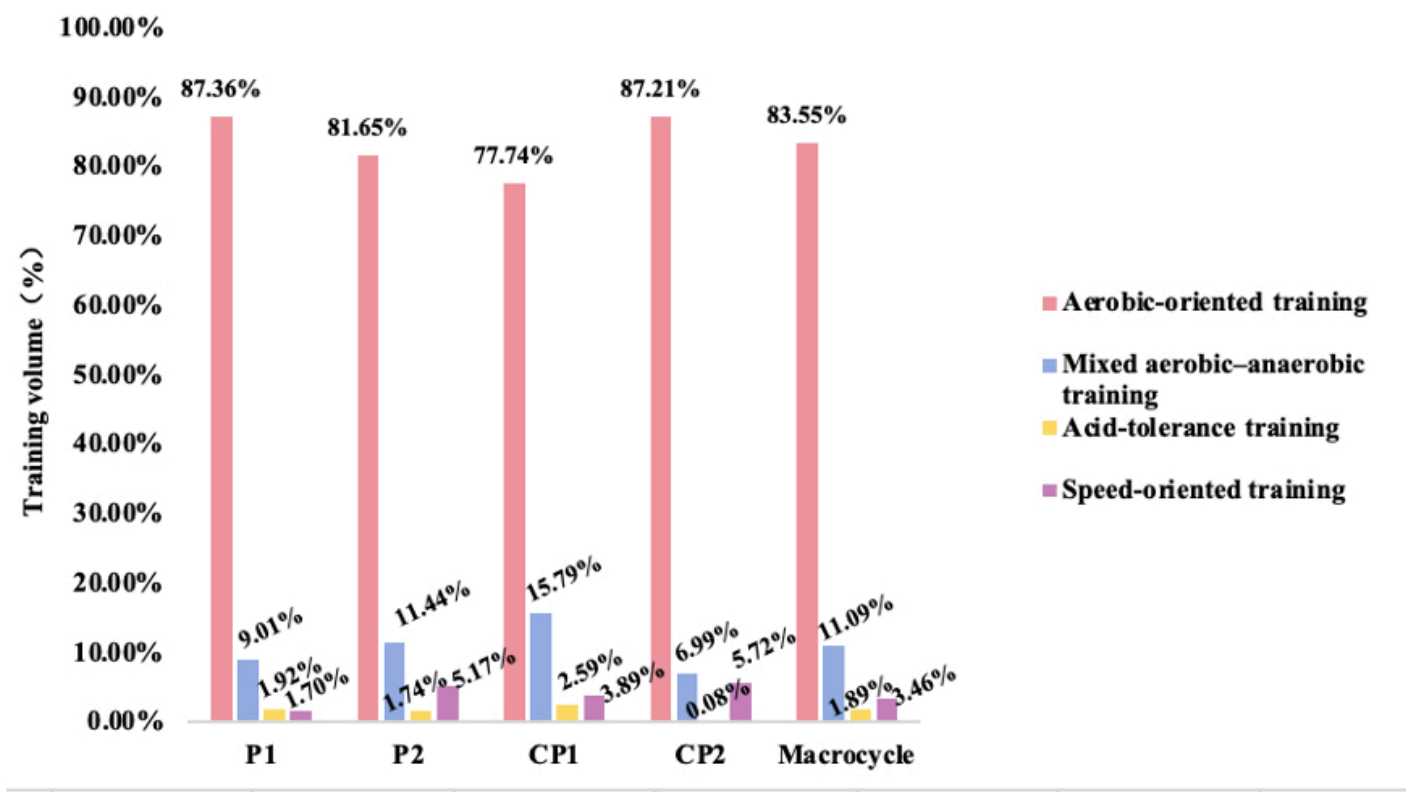


Figure 6. Distribution of on-water training volume across ability-related training categories during the preparation macrocycle and training phases

Figure 6

See image above for figure legend.