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External Match Demands, Variability and Tactical Role Differences in Elite Men's Canoe Polo

Maria Teresa Benincasa

mariateresa.benincasa@univr.it

University of Verona

Daniele Albano

University of Sannio

Silvia Coppola

University of Salerno

Claudia Costa

University of Verona

Francesco Coiro

University of Verona

Ester Celentano

University of Salerno

Enrico Serra

University of Verona

Rodolfo Vastola

University of Salerno

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Abstract

Background

Characterising match demands is fundamental to evidence-informed training in canoe polo.

Aims

To extend limited competition-derived evidence, this study quantified external match demands and their variability and explored tactical-role differences in an elite men's national team. Methods: Nine players wore 50-Hz GNSS units across five official matches. Cumulative outcomes were expressed in absolute and exposure-normalised terms. Linear mixed-effects models included match as a fixed effect and athlete as a random intercept, adjusting peak outcomes for exposure duration. Variability was quantified using intraclass correlations with 2,000 bootstrap replicates, and role differences using exhaustive athlete-level permutations with false-discovery-rate correction.

Results

Model-adjusted exposure was 20.59 min, with 887 m covered at 43.37 m·min^{-1}. Maximum speed, acceleration, and deceleration were 3.75 m·s^{-1}, 2.92 m·s^{-2}, and 4.12 m·s^{-2}. Speeds below 2 m·s^{-1} accounted for 93.55% of exposure time, whereas speeds from 2 to < 4 m·s^{-1} accounted for 6.45% of time but 22.38% of distance. Relative distance showed the highest athlete-level consistency (ICC = 0.859). Playmakers displayed greater relative distance, maximum speed, and time at 2 to < 4 m·s^{-1} than air players (all q = 0.0185), with no adjusted differences in acceleration or deceleration outcomes.

Conclusions

These results support training alignment with match demands and role-specific conditioning in elite canoe polo.

Introduction

Canoe polo is a competitive team sport played on a 35 × 23 m water-based playing area. Two teams, each comprising a maximum of eight players, of whom no more than five may be present in the playing area at any one time, compete to score goals in the opposing team's goal. Each goal measures 1.0 m in height and 1.5 m in width and is suspended with its lower inside edge 2 m above the water surface (International Canoe Federation, 2025). A match lasts 20 min and is divided into two 10-min halves separated by a 3-min interval. Play begins with a sprint towards the centre line to gain possession of the ball. Substitutions are permitted at any time and may therefore result in different individual exposure

durations (International Canoe Federation, 2025). Players may retain possession of the ball for a maximum of 5 s (International Canoe Federation, 2025).

Canoe polo is a dynamic team sport requiring a combination of complex technical skills and a broad range of physical capacities (Sheykhlouvand, Khalili, et al., 2016; Sheykhlouvand et al., 2015). Match play is characterised by intermittent high-intensity efforts, such as sprints and contests for position, interspersed with periods of low- and moderate-intensity activity (Alves et al., 2012; Forbes et al., 2013). This intermittent structure requires the integrated contribution of aerobic and anaerobic capacities, together with the technical and tactical skills specific to the discipline (Alves et al., 2012; Forbes et al., 2013; Sheykhlouvand et al., 2015; Sheykhlouvand, Khalili, et al., 2016).

The available canoe polo literature has focused primarily on athletes' anthropometric, physiological, physical, and performance characteristics, as well as their functional and nutritional profiles (Alves et al., 2012; Sheykhlouvand et al., 2015; Forbes & Sheykhlouvand, 2016; Marques-Sule et al., 2022). These contributions have helped to identify relevant athlete characteristics and physical capacities potentially associated with performance.

A sport-specific performance model may be understood as an integrated representation of the factors and demands contributing to performance within a given discipline (Vastola et al., 2012). In canoe polo, defining such a model therefore requires the combined consideration of the physiological, physical, technical, tactical, and contextual components that characterise match play. Knowledge of competitive demands can inform athlete assessment and the design of specific training programmes that reflect match conditions (Reilly et al., 2009; Bourdon et al., 2017). Within this multidimensional framework, the characterisation of external match demands represents an essential component of the performance model, as it provides objective reference values for load prescription and monitoring and for the design of training activities that reflect the demands of competition.

In athlete monitoring, external load describes the physical work performed by the athlete, whereas internal load refers to the psychophysiological responses elicited by that work (Impellizzeri et al., 2019). Wearable GPS/GNSS systems enable the quantification of indicators such as position, distance covered, speed, and changes in speed, thereby providing an objective description of the locomotor and kinematic components of competitive activity (Cummins et al., 2013). Although these technologies are now widely used in field-based team sports, particularly across the various football codes and rugby (Castillo-Rodríguez et al., 2024; Bradley et al., 2024; Dawson et al., 2024; Chun et al., 2022; Rico-González et al., 2020; Terziotti et al., 2018; Scott et al., 2016; Cummins et al., 2013), their application in canoe polo remains recent and limited (Vastola et al., 2024; Below et al., 2026).

However, GPS/GNSS-derived measures do not, in isolation, provide a direct quantification of energetic cost, internal biomechanical loading, technical actions, or tactical effectiveness and should therefore be interpreted alongside physiological, technical, tactical, and contextual information (Vanrenterghem et al., 2017). GPS data can consequently contribute to defining the external component of the canoe polo performance model by complementing, rather than replacing, the other dimensions of performance.

Despite the relevance of this information to the definition of the competitive profile, studies directly examining match demands in canoe polo remain scarce. Forbes et al. (2013) combined video-based time–motion analysis with heart-rate monitoring during three international matches. More recently, Vastola et al. (2024) used GPS devices and heart-rate monitors to describe distance, speed, acceleration, and cardiac responses in ten female athletes from the Italian national team during a simulated match, in which participation time was standardised to 10 min for each athlete. Preliminary evidence presented in a conference abstract has also proposed an initial-velocity-adjusted classification of accelerations in elite canoe polo, highlighting the need to contextualise the interpretation of absolute acceleration thresholds (Below et al., 2026). Overall, evidence remains limited regarding the integrated characterisation, through repeated observations across multiple official international matches, of total and relative distance, the distribution of time and distance across speed, acceleration, and deceleration bands, maximum values, and the variability of the principal external-load indicators.

This gap concerns not only the estimation of typical external match demands, but also the quantification of their variability. Aggregated mean values may conceal systematic differences between athletes, differences associated with individual matches, and fluctuations within the same athlete from one match to another. In elite football, high-speed and sprint-related indicators have generally shown greater match-to-match variability than global locomotor measures such as total or relative distance, indicating that typical values and variability provide complementary information on competitive demands (Gregson et al., 2010; Trewin et al., 2018). Although the magnitude of these variations cannot be transferred directly to canoe polo, this evidence suggests that estimating typical demands together with between-athlete variability, differences among matches, and within-athlete match-to-match variability may provide a more comprehensive understanding of the competitive profile.

Accordingly, the primary aim of the present study was to characterise the GPS-derived external match demands of a senior men's national canoe polo team during five official matches played within an international competition. Specifically, total and relative distance, the distribution of time and distance across predefined speed, acceleration, and deceleration bands, and maximum speed, acceleration, and deceleration were quantified. Based on previous evidence, it was hypothesised that most competitive exposure time would be accumulated in the lower speed bands and in acceleration and deceleration bands of lower magnitude, whereas the higher bands would account for progressively smaller proportions of exposure time (Forbes et al., 2013; Vastola et al., 2024). A secondary aim was to quantify the variability of these demands by examining between-athlete differences, differences observed among the five matches, and, in athletes monitored repeatedly, within-athlete match-to-match variability. Finally, as a supplementary exploratory analysis, the study examined whether the principal external-load indicators differed between the two tactical roles within the team, air players and playmakers.

Methods

Participants

The study consisted of nine athletes from the Italian senior national canoe polo team. Their average anthropometric characteristics were age 31.3 ± 3.8 years, body weight 85.8 ± 6.9 kg, and height 182.6 ± 5.4 cm. Within the sample, players were divided into "air players" (n = 4) and "playmakers" (n = 5) according to their predominant tactical role, as determined by the national-team technical staff. Air players primarily play a defensive role, focusing on blocking opponents and maintaining stable positions in the field to protect the goal. In contrast, playmakers manage offensive gameplay, orchestrate attacking actions, manage ball possessions, and move quickly to create space and shooting opportunities.

All athletes were medically cleared for international competition and were free from neuromuscular, cardiovascular, respiratory, or circulatory conditions that could limit their participation or performance. None of the participants was undergoing pharmacological treatment that could affect the study outcomes. Before the start of the study, the athletes provided informed consent following a full explanation of the procedures involved. All the athletes were informed of the potential risks associated with the study. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. This study was approved by the Ethical Committee of the Department of the Department of Human, Philosophical, and Educational Sciences at the University of Salerno (Protocol Number: 0354235).

Data collection

The study was designed as an observational repeated-measures field study. Data collection was coordinated by the head of the Center for Education and Research of the FICK (Italian Canoe Kayak Federation) and the technical director of the national teams, Prof. Rodolfo Vastola, in collaboration with the staff from the Laboratory for Innovative Teaching and Sports Performance Analysis at the University of Salerno (Unisa).

Five official matches the ECA Cup of Saint Omer in France, 2024, were included in the analysis. All matches were played at the same outdoor competition venue. The opponents were senior national teams participating in the same international competition. The Italian team recorded three wins, one draw, and one loss and completed the tournament in second place.

Individual on-field match exposure was defined as the cumulative elapsed time during which each athlete was present in the playing area across the two halves of a match. The beginning and end of each on-field period were identified by cross-referencing the GNSS timeline with match video recordings and substitution records. Warm-up, half-time, time spent on the bench, and post-match periods were excluded. Official match stoppages were retained when the athlete remained in the playing area, as these periods formed part of the athlete’s actual competitive exposure. Accordingly, individual on-field exposure represented elapsed time in the playing area rather than net regulation playing time and could therefore exceed 20 min.

Before statistical analysis, each athlete-match record was screened for data completeness and trace quality. Only records containing a complete GNSS file for all identified on-field periods, with all prespecified external-load variables available and without unresolved signal loss or implausible discontinuities in the movement trace, were retained. Satellite-count and horizontal-dilution-of-precision data were not available in the exported dataset; therefore, no numerical satellite-signal threshold was applied. The final dataset consisted of 33 valid athlete-match observations, with 7, 3, 7, 8, and 8 individual records available for matches 1–5, respectively. Athlete-match records were unavailable when an athlete was not selected for the match, did not enter the playing area, or when a complete usable GNSS recording was not available.

External-load data were collected using K-AI Wearable Tech units (KSport® World Srl, Fano, Italy). The devices recorded GNSS data at a sampling frequency of 50 Hz and integrated data from a triaxial accelerometer, gyroscope, and magnetometer, sampled at 238 Hz, through the manufacturer's Sensor Fusion processing. Each unit was inserted into the dedicated pocket of a K-Shirt, positioned on the upper back. This standardised the position of the device across athletes and was intended to limit movement of the unit relative to the body. Device positioning was checked by the research staff before each match, and athletes were monitored to ensure correct use throughout the competition.

Following each match, data were downloaded and processed using K-Fitness software (KSport® World Srl, Fano, Italy) and subsequently exported for analysis. In accordance with the manufacturer's processing settings, speed and acceleration data were retained when maintained for at least 0.40 s, whereas maximum values were identified using a minimum duration of 0.10 s. Consequently, brief values sustained for 0.10 to < 0.40 s could contribute to maximum-value outcomes without being included in the band-specific time and distance summaries.

The external-load variables included in the analysis were the total distance covered during a match (D), expressed in metres; the maximum speed achieved (SMax), originally exported in kilometres per hour and subsequently converted to metres per second ($m \cdot s^{-1}$); the maximum acceleration (AMax) and maximum deceleration (DecMax), both expressed in metres per second squared ($m \cdot s^{-2}$); and relative distance (DREL), calculated in metres per minute ($m \cdot min^{-1}$). For each athlete, the distance covered (D) and the time spent (T) were calculated within four defined speed intervals: 0 to 1 m/s (S1), 1 to 2 m/s (S2), 2 to 3 m/s (S3), and 3 to 4 m/s (S4). Thresholds for acceleration and deceleration were categorized into eight ranges: -4 to -3 m/s^2 (A1), -3 to -2 m/s^2 (A2), -2 to -1 m/s^2 (A3), -1 to 0 m/s^2 (A4), 0 to 1 m/s^2 (A5), 1 to 2 m/s^2 (A6), 2 to 3 m/s^2 (A7), and 3 to 4 m/s^2 (A8). For each range, the distance covered (D) and the time spent (T) were calculated. The speed and acceleration thresholds were defined as absolute intervals to describe the distribution of activity across the range most frequently observed during competitive match play, whereas values outside these intervals were retained within the maximum-speed, maximum-acceleration, and maximum-deceleration variables.

Data preparation and normalization

The individual athlete-match exposure was considered the analytical unit. Data from the five matches were combined into a single long-format dataset, in which each row represented the performance of one athlete in one match. Athlete identifiers were harmonized across the different worksheets, aggregate summary rows were removed, and band-specific analyses were restricted to the four predefined speed bands (S1-S4). The final dataset comprised 33 athlete-match observations from nine athletes. Individual on-field exposure times were converted into seconds and decimal minutes. Maximum speed values, originally exported by the manufacturer's software in kilometres per hour, were converted into metres per second by dividing the original values by 3.6. Maximum deceleration was originally exported as a negative value and was converted to its absolute magnitude; therefore, higher values represented more intense decelerations. This variable is hereafter referred to as maximum deceleration (DecMax).

Because individual on-field exposure differed among athletes and matches, cumulative external-load variables were retained in their absolute units and were also expressed relative to exposure duration. Relative distance was calculated by dividing total distance, expressed in metres, by individual on-field exposure, expressed in decimal minutes.

Distances accumulated within each speed, acceleration, and deceleration band were similarly divided by the athlete's total on-field exposure time and expressed in metres per minute. Thus, band-specific relative distance represented the number of metres accumulated within a given band per minute of total match exposure. Band-specific distances were also expressed as a percentage of the athlete's total distance covered during the corresponding match.

Time accumulated within each speed, acceleration, and deceleration band was converted into seconds and expressed as a percentage of the athlete's total on-field exposure during the corresponding match. Therefore, the percentage of time in each band represented the relative distribution of the athlete's match exposure independently of the total duration played.

Maximum speed, maximum acceleration, and maximum deceleration were not normalised by exposure duration because they represented peak rather than cumulative values. Instead, individual on-field exposure duration was subsequently included as a covariate in the statistical models for maximum-value outcomes to account for the greater opportunity to observe an extreme value during longer match exposures.

Three summary indicators were derived to provide interpretable measures of exposure to the upper analysed speed and acceleration bands and the higher-magnitude analysed deceleration bands, while limiting the number of inferential comparisons. The percentage of time accumulated in S3 and S4, corresponding to speeds from 2 to < 4 $m \cdot s^{-1}$, was calculated by summing the respective percentages. The percentage of time accumulated in A7 and A8, corresponding to accelerations from 2 to < 4 $m \cdot s^{-2}$, and the percentage of time accumulated in A1 and A2, corresponding to decelerations from − 4 to <-2 $m \cdot s^{-2}$, were calculated in the same manner.

Statistical analysis

The analytical dataset comprised 33 athlete-match observations from nine athletes. The analysis was conducted in four sequential stages.

First, descriptive statistics were calculated across all athlete-match observations and reported as mean ± standard deviation, median [interquartile range], and minimum-maximum values. To obtain an athlete-balanced team profile, repeated observations were averaged within each athlete and the resulting nine athlete-specific means were subsequently summarized, ensuring that each athlete contributed equally irrespective of the number of matches played.

Second, the adequacy of time normalization was evaluated for each relative external-load variable using linear mixed-effects models fitted by restricted maximum likelihood. Centered exposure duration and match were included as fixed effects and athlete as a random intercept. The exposure-duration coefficient and its 95% confidence interval were examined to identify any relevant residual association with playing time. A supplementary log-log mixed-effects model was fitted for total distance, with a coefficient compatible with 1 considered supportive of an approximately proportional relationship between distance and exposure duration. P values from the component-level normalization checks were adjusted using the Benjamini-Hochberg false-discovery-rate procedure.

Third, overall external match demands and their variability were estimated using random-intercept linear mixed-effects models fitted to all 33 observations. Match was included as a categorical fixed effect and athlete as a random intercept; centered exposure duration was additionally included for maximum speed, acceleration, and deceleration. Model-adjusted marginal means, averaged equally across the five matches, and model-based 95% confidence intervals were calculated for the principal external-load variables. Speed, acceleration, and deceleration bands were analysed descriptively using athlete-balanced percentages and relative-distance values, without separate inferential testing for each band because they represented interdependent components of the same total exposure.

Between-athlete and residual athlete-match variability were estimated from the random-intercept and residual variance components, respectively, and athlete-level intraclass correlation coefficients were calculated. For positive-valued KPIs, additional log-scale models were used to express between-athlete and residual match-to-match variability as coefficients of variation. Ninety-five percent percentile confidence intervals for the variance components and intraclass correlation coefficients were estimated using 2,000 parametric bootstrap replicates. Differences among the five matches were described using adjusted match-specific marginal means and their ranges.

Fourth, exploratory differences between air players and playmakers were examined for relative distance, maximum speed, maximum acceleration, maximum deceleration, and the percentages of time accumulated in S3-S4, A7-A8, and A1-A2. Role and match were included as fixed effects and athlete as a random intercept; centered exposure duration was additionally included for the maximum-value outcomes. Relative distance, maximum acceleration, and time in S3-S4 were analysed on their original scales, whereas maximum speed, maximum deceleration, and time in A7-A8 and A1-A2 were log-

transformed following model diagnostics. Effects were expressed as adjusted mean differences or back-transformed playmaker-to-air-player ratios.

Inference for the role effect was based on exhaustive athlete-level permutation testing across all 126 possible allocations of the nine athletes into groups of four and five, while retaining all repeated observations from each athlete within the same permuted group. Two-sided permutation p values were adjusted across the seven outcomes using the Benjamini-Hochberg procedure. Adjusted marginal means, differences or ratios, model-based 95% confidence intervals, permutation p values, and false-discovery-rate-adjusted q values were reported. Hedges' g with 95% confidence intervals was calculated from the athlete-specific means as a supplementary unadjusted standardised effect-size measure.

Model assumptions were assessed using Q-Q plots, residual-versus-fitted plots, standardised residuals, residual variance patterns, convergence status, and random-effect estimates. Shapiro-Wilk tests of residuals were used only as supplementary diagnostic information. Sensitivity analyses were conducted by excluding match 2 and by sequentially excluding one athlete at a time. All tests were two-sided, with significance set at $p < 0.05$ or $q < 0.05$ following false-discovery-rate correction. Analyses were performed using Python 3.13.5, NumPy 2.3.5, SciPy 1.17.0, statsmodels 0.14.6, and Matplotlib 3.10.8.

Results

Data availability and time-normalization checks

A total of 33 valid athlete-match observations from nine athletes were included in the analysis. The numbers of valid individual records available for matches 1-5 were 7, 3, 7, 8, and 8, respectively. Individual on-field exposure duration ranged from 12.40 to 29.42 min.

For relative distance, the mixed-effects model showed an exposure-duration coefficient of -0.219 $m \cdot min^{-1}$ per additional minute of exposure (95% CI: -0.533 to 0.096), with a standardised coefficient of -0.128 (95% CI: -0.312 to 0.056; $p = 0.172$; $q = 0.661$). In the additional log-log model, the coefficient relating total distance to exposure duration was 0.867 (95% CI: 0.702-1.032). None of the component-level time-normalization checks remained statistically significant after false-discovery-rate correction (all $q \geq 0.226$).

Overall external match demands

The principal external-load variables are presented in Table 1. Model-adjusted on-field exposure was 20.59 min (95% CI: 18.79-22.39), with a relative distance of 43.37 $m \cdot min^{-1}$ (95% CI: 38.96-47.78). Model-adjusted maximum speed, acceleration, and deceleration were 3.75 $m \cdot s^{-1}$, 2.92 $m \cdot s^{-2}$, and 4.12 $m \cdot s^{-2}$, respectively.

Table 1. Overall external match demands

Variable	Athlete-balanced mean ± SD	Model-adjusted mean (95% CI)	Observed range
On-field exposure, min	20.82 ± 2.65	20.59 (18.79-22.39)	12.40-29.42
Total distance, m	885 ± 214	887 (741-1034)	481-1499
Relative distance, $m \cdot min^{-1}$	42.35 ± 7.27	43.37 (38.96-47.78)	25.87-57.55
Maximum speed, $m \cdot s^{-1}$	3.72 ± 0.30	3.75 (3.53-3.96)	3.22-4.58
Maximum acceleration, $m \cdot s^{-2}$	2.93 ± 0.36	2.92 (2.67-3.16)	1.80-4.10
Maximum deceleration, $m \cdot s^{-2}$	4.13 ± 0.71	4.12 (3.67-4.56)	2.30-6.20

Athlete-balanced values were calculated by first averaging repeated observations within each athlete and then summarizing the nine athlete-specific means. Model-adjusted means were averaged equally across the five matches. Maximum-value outcomes were adjusted for individual exposure duration.

Speed-band profile

Across S1-S4, the athlete-balanced percentages of exposure time were 74.86 ± 7.27%, 18.69 ± 5.21%, 5.65 ± 1.68%, and 0.81 ± 0.62%, respectively. The corresponding percentages of total distance were 40.68 ± 8.47%, 36.90 ± 4.71%, 18.80 ± 3.39%, and 3.58 ± 2.09%, while relative distance within the four bands was 16.62 ± 1.22, 15.94 ± 4.54, 8.12 ± 2.42, and 1.65 ± 1.19 $m \cdot min^{-1}$, respectively. S3-S4 jointly accounted for 6.45% of exposure time and 22.38% of total distance. Figure 1 displays the time and distance distributions across the four speed bands.

Acceleration and deceleration-band profile

The athlete-balanced percentages of exposure time in A1-A8 were 0.10 ± 0.07%, 0.48 ± 0.17%, 3.18 ± 0.70%, 47.41 ± 0.96%, 44.10 ± 1.34%, 3.80 ± 0.81%, 0.60 ± 0.25%, and 0.09 ± 0.06%, respectively. The corresponding percentages of total distance were 0.23 ± 0.12%, 0.76 ± 0.26%, 4.62 ± 1.10%, 44.11 ± 1.66%, 42.07 ± 2.23%, 6.44 ± 1.41%, 1.23 ± 0.52%, and 0.30 ± 0.14%. Relative distance in A1-A8 was 0.10 ± 0.05, 0.32 ± 0.13, 1.98 ± 0.57, 18.70 ± 3.47, 17.75 ± 2.80, 2.76 ± 0.81, 0.52 ± 0.21, and 0.12 ± 0.06 $m \cdot min^{-1}$, respectively. The combined percentages of exposure time accumulated in A7-A8 and A1-A2 were 0.69 ± 0.30% and 0.58 ± 0.21%, respectively. Figure 2 displays the corresponding time and distance distributions.

Between-athlete and match-to-match variability

Intraclass correlation coefficients, between-athlete and residual coefficients of variation, and adjusted match-mean ranges are presented in Table 2. Athlete-level ICCs ranged from 0.161 for maximum deceleration to 0.859 for relative distance. The ICC for total distance was 0.661 (95% bootstrap CI: 0.187-0.858), whereas the ICC for relative distance was 0.859 (95% bootstrap CI: 0.546-0.949). ICCs for

maximum speed, maximum acceleration, and maximum deceleration were 0.325, 0.428, and 0.161, respectively.

For the aggregated band indicators, ICCs were 0.694 for time accumulated in S3-S4, 0.733 for time accumulated in A7-A8, and 0.613 for time accumulated in A1-A2.

The adjusted match-specific mean for relative distance ranged from 37.87 to 48.04 $m \cdot min^{-1}$ across the five matches. The corresponding ranges were 723-1089 m for total distance, 3.59-3.89 $m \cdot s^{-1}$ for maximum speed, 2.67-3.09 $m \cdot s^{-2}$ for maximum acceleration, and 3.90-4.38 $m \cdot s^{-2}$ for maximum deceleration.

Table 2. Variability of the principal external-load variables

Variable	Athlete ICC (95% bootstrap CI)	Between-athlete CV, %	Residual match-to-match CV, %	Adjusted match-mean range
On-field exposure	0.187 (0.000-0.557)	9.8	17.3	16.72-23.86 min
Total distance	0.661 (0.187-0.858)	24.9	15.9	723-1089 m
Relative distance	0.859 (0.546-0.949)	16.2	6.9	37.87-48.04 $m \cdot min^{-1}$
Maximum speed	0.325 (0.000-0.667)	6.4	8.4	3.59-3.89 $m \cdot s^{-1}$
Maximum acceleration	0.428 (0.000-0.741)	10.8	12.5	2.67-3.09 $m \cdot s^{-2}$
Maximum deceleration	0.161 (0.000-0.534)	11.9	22.2	3.90-4.38 $m \cdot s^{-2}$
Time in S3-S4	0.694 (0.247-0.883)	36.1	24.4	5.77-8.99%
Time in A7-A8	0.733 (0.315-0.903)	68.5	27.3	0.66-0.77%
Time in A1-A2	0.613 (0.136-0.837)	48.1	28.6	0.50-0.62%

ICC confidence intervals were obtained using 2,000 parametric bootstrap replicates. Residual CV represents the remaining athlete-match variability after accounting for athlete and match.

Exploratory differences between tactical roles

Model-adjusted role comparisons are reported in Table 3.

Relative distance was 36.86 $m \cdot min^{-1}$ (95% CI: 33.54-40.18) in air players and 48.40 $m \cdot min^{-1}$ (95% CI: 45.67-51.13) in playmakers. The adjusted difference was 11.54 $m \cdot min^{-1}$ (95% CI: 7.28-15.80;

permutation p = 0.0079; q = 0.0185).

Maximum speed was 3.35 m·s⁻¹ (95% CI: 3.17-3.53) in air players and 3.95 m·s⁻¹ (95% CI: 3.83-4.07) in playmakers. The playmaker-to-air-player ratio was 1.179 (95% CI: 1.108-1.255; permutation p = 0.0079; q = 0.0185).

The percentage of time accumulated in S3-S4 was 5.05% (95% CI: 3.80-6.29) in air players and 8.26% (95% CI: 7.29-9.23) in playmakers. The adjusted difference was 3.22 percentage points (95% CI: 1.66-4.77; permutation p = 0.0079; q = 0.0185).

No false-discovery-rate-adjusted differences were found for maximum acceleration (q = 0.881), maximum deceleration (q = 0.222), time accumulated in A7-A8 (q = 0.815), or time accumulated in A1-A2 (q = 0.733).

Table 3. Model-adjusted differences between air players and playmakers

Outcome	Air players, adjusted mean (95% CI)	Playmakers, adjusted mean (95% CI)	Adjusted effect (95% CI)	Permutation p	FDR q	Hedges' g (95% CI)
Relative distance, m·min⁻¹	36.86 (33.54-40.18)	48.40 (45.67-51.13)	+11.54 (7.28-15.80)	0.0079	0.0185	3.34 (0.70-5.97)
Maximum speed, m·s⁻¹	3.35 (3.17-3.53)	3.95 (3.83-4.07)	Ratio 1.179 (1.108-1.255)	0.0079	0.0185	5.01 (1.47-8.55)
Maximum acceleration, m·s⁻²	2.89 (2.46-3.31)	2.93 (2.61-3.26)	+0.05 (-0.49-0.58)	0.8810	0.8810	0.07 (-1.52-1.65)
Maximum deceleration, m·s⁻²	3.47 (2.88-4.18)	4.25 (3.80-4.76)	Ratio 1.224 (0.986-1.519)	0.1270	0.2222	0.77 (-0.89-2.43)
Time in S3-S4, %	5.05 (3.80-6.29)	8.26 (7.29-9.23)	+3.22 pp (1.66-4.77)	0.0079	0.0185	2.63 (0.33-4.93)
Time in A7-A8, %	0.52 (0.27-1.02)	0.66 (0.37-1.18)	Ratio 1.261 (0.522-3.046)	0.6984	0.8148	0.05 (-1.54-1.64)
Time in A1-A2, %	0.44 (0.27-0.72)	0.56 (0.37-0.86)	Ratio 1.290 (0.672-2.476)	0.5238	0.7333	0.23 (-1.36-1.82)

Differences are reported for outcomes analysed on their original scale; ratios represent back-transformed effects from log-scale models. pp, percentage points. Hedges' g was calculated from unadjusted athlete-specific means.

Sensitivity analyses and model diagnostics

After excluding match 2, the estimated role effects were 11.55 m·min⁻¹ for relative distance (95% CI: 7.31-15.78; permutation p = 0.0079), 1.180 for maximum speed (1.108-1.257; permutation p = 0.0079), 0.04 m·s⁻² for maximum acceleration (-0.49 to 0.57; permutation p = 0.8810), 1.232 for maximum deceleration (1.003-1.515; permutation p = 0.1032), 3.22 percentage points for time in S3-S4 (1.62-4.82; permutation p = 0.0159), 1.262 for time in A7-A8 (0.525-3.032; permutation p = 0.7063), and 1.291 for time in A1-A2 (0.682-2.446; permutation p = 0.5238).

Across the leave-one-athlete-out analyses, estimated effects ranged from 10.27 to 12.77 m·min⁻¹ for relative distance, 1.170 to 1.187 for maximum speed, -0.152 to 0.178 m·s⁻² for maximum acceleration, 1.105 to 1.327 for maximum deceleration, 2.69 to 3.63 percentage points for time in S3-S4, 0.805 to 1.594 for time in A7-A8, and 0.919 to 1.505 for time in A1-A2. All role models converged, and no observation had an absolute standardised residual greater than 3. The maximum-speed model yielded an athlete random-intercept variance at or near zero. Residual-scale heterogeneity signals were observed for maximum speed and time in S3-S4; no corresponding diagnostic signal was detected for the remaining models.

Discussion

Overall external match demands

The model-adjusted estimates characterize the typical whole-match external load observed in the present team. Athletes covered approximately 887 m during 20.59 min of on-field exposure, corresponding to a relative distance of 43.37 m·min⁻¹. The substantial ranges observed for exposure duration, total distance, and relative distance indicate that absolute and relative measures provide complementary information: total distance quantifies the volume accumulated during participation, whereas relative distance describes the locomotor density sustained during the time actually spent in the playing area. The relative distance corresponds to a mean translational rate of approximately 0.72 m·s⁻¹, markedly lower than the model-adjusted maximum speed of 3.75 m·s⁻¹. This difference shows that the average whole-exposure movement rate remained well below the highest speed reached, although average and maximum values alone do not indicate the frequency or duration of faster actions. The distribution across the speed bands therefore provides a more detailed characterization of how the overall external load was accumulated.

Speed-band profile

The speed-band distribution confirmed that match activity was accumulated predominantly in the two lower bands. S1-S2 accounted for 93.55% of exposure time and 77.58% of total distance, whereas S3-S4 represented only 6.45% of exposure time but contributed 22.38% of the distance covered. Therefore, movements between 2 and < 4 $m \cdot s^{-1}$ were temporally limited but made a proportionally greater contribution to total displacement. This pattern is consistent with Forbes et al. (2013), who found that slow-to-moderate forward paddling, contesting for position, and resting or gliding accounted for most international match time, while sprinting represented only a small proportion. A predominance of the lower speed bands was also observed by Vastola et al. (2024) during a simulated female canoe polo match.

A broadly comparable organization has been described in other intermittent team sports. In elite soccer, lower-intensity locomotor activities account for most match play, whereas higher-intensity actions are less frequent and vary according to playing position (Bloomfield et al., 2007; Mohr et al., 2008). In basketball, time-motion analyses have similarly shown that most live playing time is spent in low- or moderate-intensity activity, with higher-intensity actions occupying a smaller proportion of the game (McInnes et al., 1995; Scanlan et al., 2012). These comparisons support the broader intermittent structure identified in canoe polo, although the magnitudes cannot be directly compared because of differences in locomotor modality, playing area, match duration, and intensity thresholds.

Water polo provides a relevant, although indirect, comparison with another aquatic intermittent team sport. During international women's competition, D'Auria and Gabbett (2008) reported exercise bouts lasting 7.4 ± 2.5 s, interspersed with comparatively longer recovery periods, with an exercise-to-rest ratio of approximately 1:1.6. Similarly, Tan et al. (2009) recorded approximately 330 discrete movements per match, corresponding to a change in activity every 6.2 s, together with 54 high-intensity activities, or approximately one every 38.4 s. These findings describe a match structure characterised by frequent transitions between activities and brief, intermittent high-intensity efforts. Although water polo and canoe polo differ substantially in their propulsion mechanics, this temporal organization is broadly consistent with the present canoe polo profile, in which most exposure was accumulated in the lower speed bands and higher-speed movements occupied a limited proportion of match time.

The predominance of lower kayak speeds should not, however, be equated with a low physiological demand. Forbes et al. (2013) reported that approximately 69% of international match time was performed above the heart rate associated with the ventilatory threshold, despite the small temporal contribution of sprinting. This apparent dissociation may reflect the demands of contesting for position, ball handling, turning, kayak stabilization, and other actions that are not fully represented by translational speed. Consequently, the present speed bands describe the external locomotor distribution but cannot be assigned directly to specific aerobic, glycolytic, or phosphagen energy pathways. Canoe-polo-specific training studies have shown that paddling-based interval training can improve both aerobic and anaerobic performance, supporting the relevance of both capacities to the discipline, but they do not establish the metabolic contribution of each GPS speed band during match play (Sheykhlouvand, Khalili, et al., 2018).

Acceleration and deceleration profile

The acceleration and deceleration profile was strongly concentrated in A4 and A5, which together accounted for 91.51% of exposure time and 86.18% of total distance. As these bands represented changes in velocity between − 1 and < 1 $m \cdot s^{-2}$, most of the monitored exposure was characterised by relatively small variations in kayak speed. This finding should not be equated with low movement speed or low physiological demand, because acceleration describes the rate of change in velocity rather than the velocity attained or the internal load generated by the action. A similar predominance of the central acceleration and deceleration bands was observed by Vastola et al. (2024) during a simulated canoe polo match.

Conversely, A7-A8 and A1-A2 each accounted for less than 1% of exposure time, indicating that higher-magnitude changes in velocity occurred briefly. These actions may plausibly have been associated with phases requiring rapid changes in kayak motion, such as sprinting for possession, offensive-defensive transitions, abrupt repositioning, or contests for position, which have been identified among the more demanding components of canoe polo match play (Forbes et al., 2013). More generally, rapid decelerations are commonly used in multidirectional team sports to reduce momentum before changing direction or following a faster action (Harper et al., 2022; McBurnie et al., 2022).

The limited time accumulated in the upper absolute bands may also partly reflect the classification method. Maximal achievable acceleration decreases as initial velocity increases, meaning that fixed absolute thresholds can underestimate demanding accelerations initiated from an already elevated speed (Sonderegger et al., 2016). Preliminary canoe-polo-specific evidence similarly showed that an initial-velocity-adjusted approach identified more high-intensity accelerations than conventional absolute thresholds (Below et al., 2026). Accordingly, the A1-A8 bands should be interpreted as descriptive categories of absolute changes in kayak velocity rather than individualized measures of acceleration intensity.

Between-athlete and match-to-match variability

Relative distance showed the most consistent match-to-match profile, combining a high athlete-level ICC with the lowest residual CV among the principal KPIs. Within the observed team, locomotor density therefore appeared to reflect relatively consistent differences between athletes and to fluctuate less within the same athlete across matches than total distance or peak variables. Conversely, the lower ICCs and greater residual variability observed for maximum speed, acceleration, and particularly deceleration suggest that peak values were more dependent on the specific athlete-match exposure. The upper-band indicators combined moderate-to-high ICCs with large between-athlete and residual CVs, indicating both marked individual heterogeneity and appreciable match-to-match variation. The ranges of the adjusted match means further showed that external demands were not constant across the five matches. A similar pattern has been reported in elite soccer, where total distance per minute showed the lowest match-to-match variability, whereas sprint and high-speed metrics were substantially more variable (Gregson et al., 2010; Trewin et al., 2018).

Differences between tactical roles

The marked between-athlete consistency observed for relative distance was accompanied by a clear role-related pattern. Playmakers showed greater relative distance, maximum speed, and time accumulated in S3-S4 than air players, whereas no role differences emerged for maximum acceleration, maximum deceleration, or exposure to A7-A8 and A1-A2. Within the tactical organization of the present team, the distinction between roles therefore appeared to concern primarily the amount and speed of translational movement rather than the selected acceleration and deceleration indicators. The greater locomotor demands observed in playmakers are consistent with their responsibility for organizing ball possession and offensive actions and for moving to create space, whereas air players performed more position-oriented defensive tasks. However, the lower GPS-derived locomotor demands of air players should not be interpreted as a lower overall match load, because GNSS does not quantify physical contests, kayak stabilization, or ball-related actions.

Previous canoe polo research has also reported position-related differences in aerobic capacity and anthropometric characteristics, supporting the broader principle that the requirements of the discipline may vary according to playing function (Sheykhlouvand & Forbes 2018). Position-dependent external demands have similarly been documented in professional soccer, where movement profiles vary according to tactical role, although this comparison should remain qualitative because of the substantial differences between terrestrial running and kayak locomotion (Bloomfield et al., 2007; Beato et al., 2024).

Practical implications

The competition-derived reference values identified in this study can support the design and monitoring of canoe polo training by providing targets for total distance, relative distance, peak speed, and exposure to specific speed and acceleration bands. Training drills can therefore be compared with the demands observed during official matches to determine whether they reproduce the required locomotor volume and intensity. The high athlete-level consistency observed for relative distance also supports the use of individual match profiles as reference values for longitudinal monitoring, rather than relying exclusively on team averages (Bourdon et al., 2017).

The role-related findings provide an additional basis for targeted conditioning. Playmakers may require training tasks characterised by greater relative distance, higher peak speeds, and more frequent exposure to S3-S4, reflecting the greater locomotor demands observed in competition. Conversely, the absence of clear role differences in maximum acceleration, maximum deceleration, and exposure to the upper acceleration and deceleration bands suggests that the capacity to rapidly change kayak velocity should remain a common component of preparation for both roles. Paddling-based high-intensity interval and sprint-interval training may be particularly useful within this framework, as previous studies in professional canoe polo athletes have reported improvements in aerobic capacity and anaerobic power following these training methods (Sheykhlouvand & Forbes, 2018; Sheykhlouvand, Gharaat, et al., 2018).In practical terms, the present study provides an initial set of competition-specific benchmarks

that coaches can use to prescribe, differentiate, and evaluate training according to both individual and tactical-role demands, thereby contributing to a more evidence-based preparation model for high-level canoe polo.

Limitations and future perspectives

A major strength of this study was the repeated monitoring of elite athletes during official international competition, which provided ecologically valid reference values for canoe polo external match demands. Nevertheless, the findings should be interpreted in relation to a single national team, nine athletes, five matches, and an unequal number of observations across athletes and matches. In addition, the absolute speed and acceleration bands were not individualized, and the absence of concurrent internal-load measures and event-based video coding prevented the recorded demands from being linked directly to physiological responses or specific technical–tactical actions. Future studies should therefore extend the analysis to larger samples, multiple teams and competitions, and integrate GNSS data with heart rate, perceived exertion, and synchronized match-event coding. The use of acceleration classifications adjusted for initial velocity and the analysis of the most demanding passages of play could further refine the current performance profile and support the development of more generalizable and competition-specific training benchmarks (Impellizzeri et al., 2019; Vanrenterghem et al., 2017; Below et al., 2026).

Conclusions

This study provides a competition-based characterization of the external match demands of elite men's canoe polo. Match activity was predominantly accumulated in the lower speed and lower-magnitude acceleration and deceleration bands, whereas higher-speed and higher-magnitude actions occurred for shorter periods. Relative distance showed the greatest consistency between matches at the athlete level, while peak variables were more variable across individual match exposures. Playmakers demonstrated greater locomotor density, maximum speed, and exposure to S3–S4 than air players. Overall, these findings provide initial team- and role-specific reference values that may support the monitoring and design of training in high-level canoe polo.

Declarations

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Disclosure statement

No potential conflict of interest was reported by the author(s)

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Data availability

The data are available at the following link: https://figshare.com/s/1a5f3025306d461cadce

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Figures

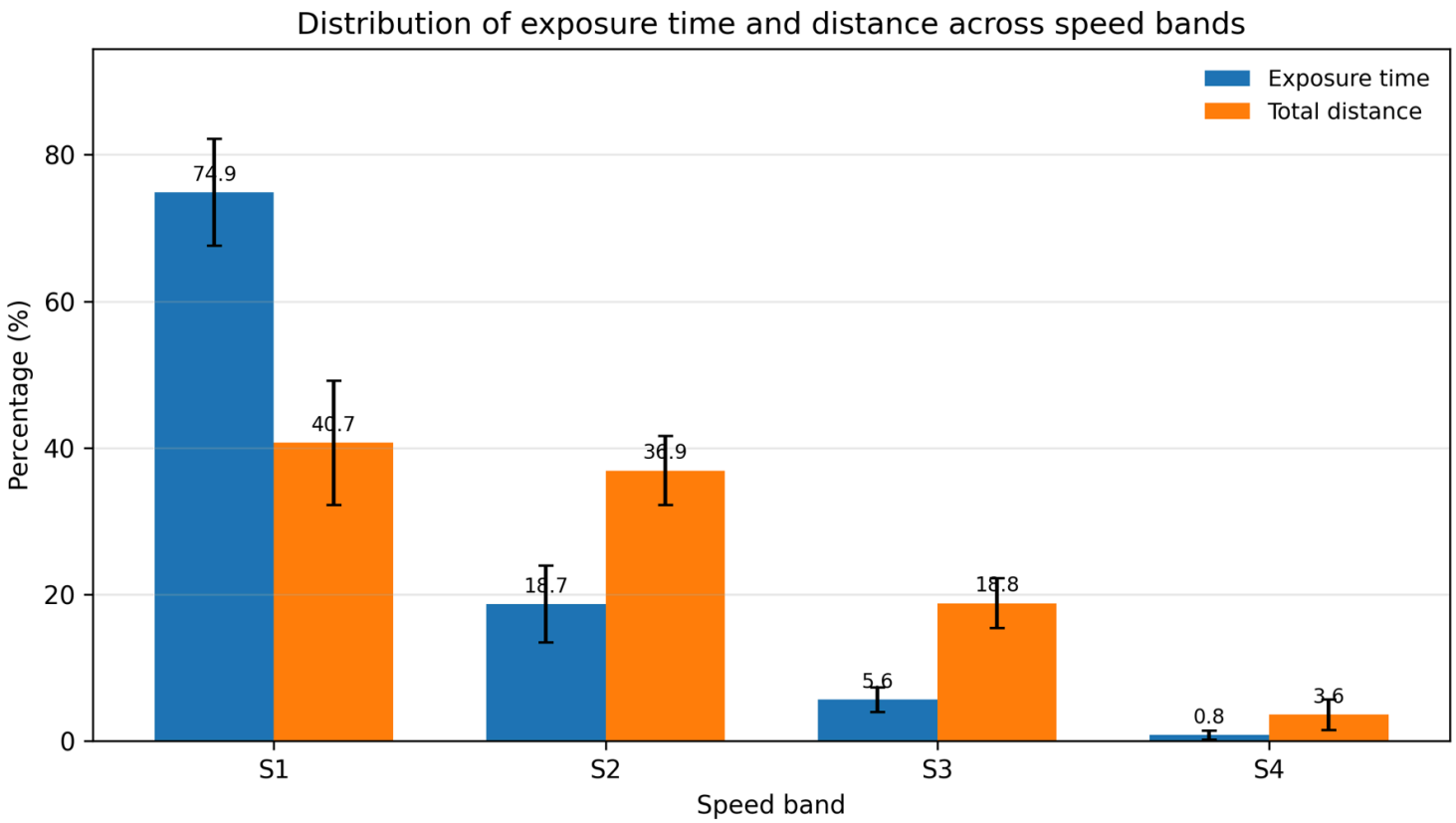


Figure 1

Athlete-balanced distribution of exposure time and total distance across speed bands. Bars and error bars represent mean ± SD of the nine athlete-specific means.

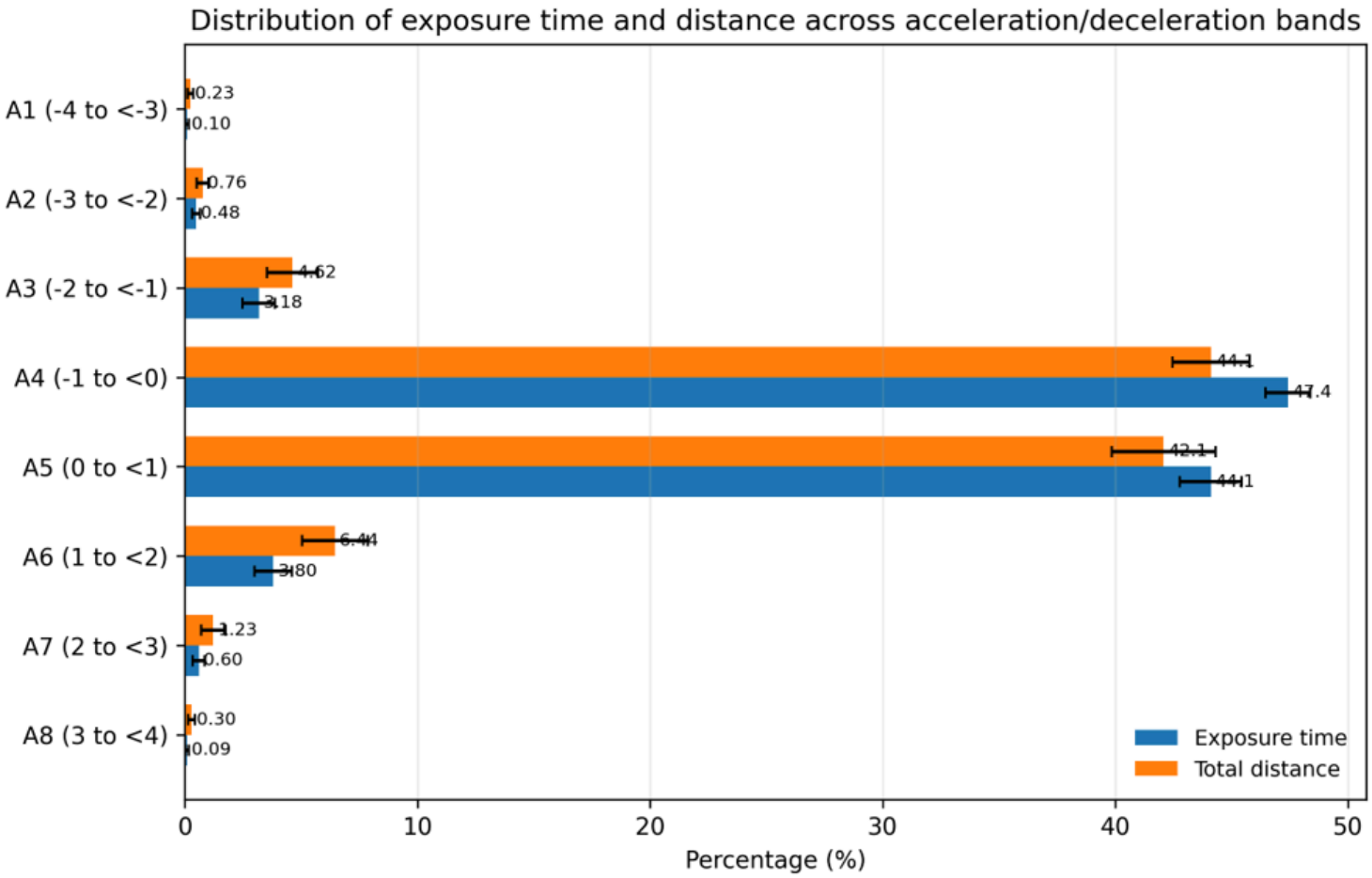


Figure 2

Athlete-balanced distribution of exposure time and total distance across acceleration and deceleration bands. Bars and error bars represent mean ± SD of the nine athlete-specific means.