



OPEN Variations in the technical performance of elite female volleyball: evidence from a new round model

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Volleyball athletes' performance can vary between different micro-phases of the competition. This study aimed to investigate distinctions in volleyball athletes' technical performance among rounds employing a novel volleyball round model. We further assessed how technical performance relates to attack outcome categories (point, continuation, error) across rounds. Data from 20 matches in the 2023/2024 Chinese Women's Volleyball Super League were analyzed using descriptive statistics, chi-square tests, and multiple logistic regression analysis. The proposed model enabled a round-specific description of technical performance and helped reveal round-to-round variation. Technical performance varied across rounds. Associations between technical variables and attack outcomes also differed by round. In Round 1, serve type showed the strongest association with attack outcomes. The jump-float serve was the most frequently used technique, while the power jump serve was more often linked with errors. In Round 2, attacks were initiated under faster tempos, and attack tempo showed the strongest association with attack outcomes. In contrast, Round 3 presented adverse conditions for attack, with blocking exerting pronounced influences on attack outcome categories. Technical performance in Rounds 4 and 5 displayed uniform patterns and attack outcomes in these rounds were statistically comparable to those in Round 2.

Keywords Female athlete, Match analysis, Round, Technical performance

Match analysis (MA) is a cornerstone of modern competitive sport¹, systematically quantifying key events and parameters to explain performance and to inform training and match strategies^{2–4}. Volleyball has attracted considerable scholarly attention within match analysis research⁵. Existing studies have examined gender-based performance differences^{6,7}, phase-specific variations^{8,9}, and differences in technical execution across diverse scenarios^{10–12}. Recent research has increasingly focused on identifying factors associated with match outcomes, including efforts to predict final results^{11,13}.

Volleyball differs from many team sports in three ways—indirect confrontation, linearity, and action sustainability—which make its rallies suitable for phase-based analysis. (1) Indirect confrontation: Originating from the net that separates the two teams' playing areas, this feature is reinforced by strict rules restricting athlete movement within designated zones¹⁴. Teams influence opponents indirectly through actions such as attacking and blocking, in contrast to the direct physical interactions typical of sports such as football and basketball. (2) Linearity: Volleyball's clearly defined action boundaries facilitate the identification of athlete actions, accentuating the sequential progression of play. Teams engage with the ball in a legally mandated order until the rally concludes^{15,16}. (3) Action sustainability: Unlike other indirect-confrontation sports (e.g., table tennis), volleyball allows multiple contacts under the three-contact constraint, enabling teams to tactically regulate ball trajectory and speed within a rally¹⁴. Consequently, the identification of action sequences and phases within rallies has become a focal point in volleyball research⁹. By analyzing variation across phases or critical periods, researchers can describe evolving match characteristics and provide evidence to inform tactical design.

However, phase-based findings in volleyball match analysis are highly sensitive to contextual factors (e.g., competition level, rule environment, and sample composition). When such factors are not controlled, heterogeneity in samples and operational definitions can limit cross-study comparability and the generalizability of proposed match-structure representations¹⁷. Moreover, women's and men's volleyball show systematic differences in match constraints and performance profiles, suggesting that within-rally structure models require sex-specific evaluation rather than being assumed transferable across sexes^{18,19}. Importantly, although round-

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and Complex-based frameworks have been widely applied, it remains unclear whether a process-ordered round representation—and the technical–tactical associations it implies across successive rounds—holds in elite women’s competition under stable contextual conditions. Because the proposed round model is at an early stage, we focus on an elite women’s league as a relatively homogeneous setting to (i) establish stable operational definitions, and (ii) provide an initial feasibility evaluation of the revised round model before testing its external validity in broader datasets. This focus is also consistent with evidence that women’s volleyball exhibits distinct phase sequencing patterns that warrant dedicated investigation¹⁴.

Therefore, phase segmentation and the selection of technical variables should be considered together: a phase model specifies when actions occur, whereas technical variables describe what actions are executed and how they relate to outcomes. The structure of a volleyball match, often framed as game-set-rally²⁰, is further delineated into rounds. In this context, a round can be defined as a team’s sequence from gaining ball control to returning the ball over the net. A new round begins when the opposing team gains control and initiates its own sequence²¹. Each net crossing can be treated as a natural boundary between successive rounds. Another widely used framework is the Complex model, which classifies phases based on typical tactical scenarios and action chains¹⁴. For example, Complex I is commonly used to represent side-out sequences (serve reception–set–attack), whereas Complex II often represents transition sequences involving block/defense–set–counterattack¹⁴. Over time, the Complex system has expanded into a more detailed phase-division framework with multiple categories^{22,23}. This system enables researchers to compare action patterns and tactical characteristics across phases, particularly in side-out contexts⁹.

Although round- and Complex-based approaches have been used to describe within-rally dynamics, important limitations remain. The Complex model is inherently situational: phases are defined by typical tactical contexts and action chains, which aids interpretation but does not follow the rally strictly in the objective sequence of play, making phases beyond the initial serve–reception sequence difficult to align temporally across rallies²⁴. In addition, round definitions may not explicitly accommodate block-triggered transitions, where a blocked attack can immediately reshape the tactical situation and can yield consecutive offensive sequences for the same team without a clear net-crossing boundary. Furthermore, non-standardized classification practices reduce cross-study comparability and hinder the comprehensive application of the Complex model²⁵. Taken together, these issues indicate that a complementary, process-ordered match-structure representation is still lacking—one that organizes within-rally events according to the objective sequence of play (i.e., ball-control changes and net crossings), rather than relying solely on context-defined scenarios. To address this gap, the present study proposes a round model that uses the objective progression of play as its organizing principle, offering a new observation perspective to describe rallies as an ordered process while remaining compatible with situational Complex interpretations^{14,17}. Conceptually, the proposed round model is a match-structure and observation framework that standardizes within-rally description in the objective order of play (ball-control changes and net crossings), rather than a data-fitted predictive model optimized for a specific dataset.

To clarify the technical variables central to this study, we operationalized the key actions that structure a rally—serve, first contact (reception/defense), setting, attack, and block—because these actions form the functional backbone of phase-based frameworks such as the game-complex model (e.g., K0, KI, and transition complexes). Prior complex-based research indicates that technical–tactical characteristics (e.g., setting conditions and attack tempo) vary across phases and relate to attacking effectiveness under different constraints. For example, prior work reported that certain complexes (e.g., KIII) may feature more “ideal” setting conditions and quicker tempos, underscoring that spatiotemporal organization is not uniform across phases and may shift with game context²³. Similarly, Complex-dependence has been emphasized in systemic approaches, suggesting that the characteristics of one phase can shape the probability and structure of subsequent phases, and that training should prepare athletes to operate under both ideal and non-ideal conditions (e.g., non-ideal setting and slower tempos) rather than relying only on “perfect” scenarios²². Serve was characterized by serve type (power jump serve, jump-float serve, standing serve) and serve zone because serving represents a distinct initial phase (K0/Round 1) and provides an early constraint on how rallies develop. Spatial context was captured through reception zone, setting zone, and attack zone using the official six court zones (1–6), enabling comparisons of where the first contact, second contact, and final contact occur across micro-phases. Attack tempo (fast, simultaneous, slow) was coded as a spatiotemporal descriptor of offensive organization, reflecting the synchronization between the setter’s contact and the attacker’s approach. This construct is consistent with Complex-based evidence showing that tempo, together with setting zone and block organization, can be statistically associated with attack quality outcomes when modeled using multinomial approaches²⁴. The final contact was described by attack type (strong attack, placed attack, tip) to represent different technical intentions and risk–reward trade-offs, whereas net defense was represented by block opposition (no-block, single, double, triple), a standard variable repeatedly integrated in Complex-related instruments and composite-variable systems²³. Finally, attack outcomes were coded as point, error, or continuation to enable round-specific comparisons of effectiveness versus risk while remaining comparable with outcome categorizations widely used in match analysis. Collectively, these variables provide an interpretable bridge between phase-based models (when actions occur and under what constraints) and actionable performance descriptors (what actions are executed, where they occur, and how they relate to outcomes) in elite women’s volleyball.

Accordingly, a model that can preserve temporal order while retaining interpretable action variables is needed. In conclusion, substantial opportunities persist for advancing research into the microstructure of volleyball games. Developing a model that better aligns with volleyball’s within-rally dynamics is important for addressing current research questions in match analysis. To our knowledge, no previous study has explicitly examined round-specific technical–tactical patterns using a process-ordered round framework that accounts for block-triggered transitions in elite women’s volleyball. Accordingly, this study proposes a revised round model to provide a more consistent framework for within-rally analysis and to examine how specific technical actions

relate to outcomes across rounds. The following hypotheses are proposed: (1) The technical performance of female athletes varies across different rounds of the game. (2) Associations between technical performance and attack outcome categories (point, continuation, error) differ by round.

Methods

Match samples

A total of 20 matches from the qualifying rounds, semi-finals, and finals of the 2023/2024 Chinese Women's Volleyball Super League were analyzed. These matches, featuring the top eight teams, encompassed 75 sets and recorded 8,915 instances of offensive and defensive actions. The variables analyzed included positional data and specific gameplay actions executed by athletes during ball contact. Match videos were obtained from publicly accessible online broadcasts available on YouTube and Migu Video. The study was purely observational: only de-identified, aggregate performance variables were extracted, and no video clips or identifiable images were reproduced or redistributed.

Ethics and permissions

This study was observational and based on publicly accessible official match replays available on YouTube and Migu Video. No intervention or interaction with athletes occurred, and no private, sensitive, or personally identifiable information was collected. Only de-identified, aggregate performance variables were extracted for analysis, and no video clips, screenshots, or identifiable images were reproduced, redistributed, or published. Formal IRB approval was not obtained because the study relied on publicly available broadcasts and involved no identifiable private data; the recordings were used solely for non-commercial research analysis in a manner intended to respect platform terms and the rights of content owners.

Variables

The selection and definition of variables were guided by previous research. The final set of verified variables included:

1. **Serve Type.** The serve type was categorized into three distinct types based on the server's motion and the volleyball's flight characteristics: (a) Power jump serve²⁶, executed by striking the ball with significant force during the jump, generating high velocity and spin; (b) Jump-float serve²⁷, executed by striking the ball mid-jump, but with minimal rotation during its trajectory; and (c) Standing serve²⁶, executed while standing on the ground, resulting in slower ball velocity. Serve type is typically observed exclusively in Round 1, a pattern that also applies to the serve zone.
2. **Serve Zone.** The serve zone was defined as the specific area of the court where the server delivers the ball. This rectangular area measures nine meters in width and is situated behind the baseline. It is divided into three equally sized regions: Zone 1, Zone 6, and Zone 5, arranged from right to left.
3. **Reception Zone:** The reception zone was defined as the area where an athlete receives a serve or makes the first contact (excluding blocking) following an opponent's attack. It is divided into six zones (Fig. 1a): the frontcourt includes Zone 2, Zone 3, and Zone 4, each measuring 3 by 3 m, while the backcourt includes Zone 1, Zone 6, and Zone 5, each measuring 6 by 3 m.
4. **Setting Zone:** The setting zone was defined as the area where setting, or the second contact, occurs²⁶. The division of the setting zone mirrors that of the reception zone, with six zones in corresponding positions (Fig. 1b). However, the setting zone encompasses extended areas, such as off-field regions on the left and right sides (Zones 1, 2, 4, and 5) and areas behind the baseline (Zones 1, 6, and 5). According to FIVB

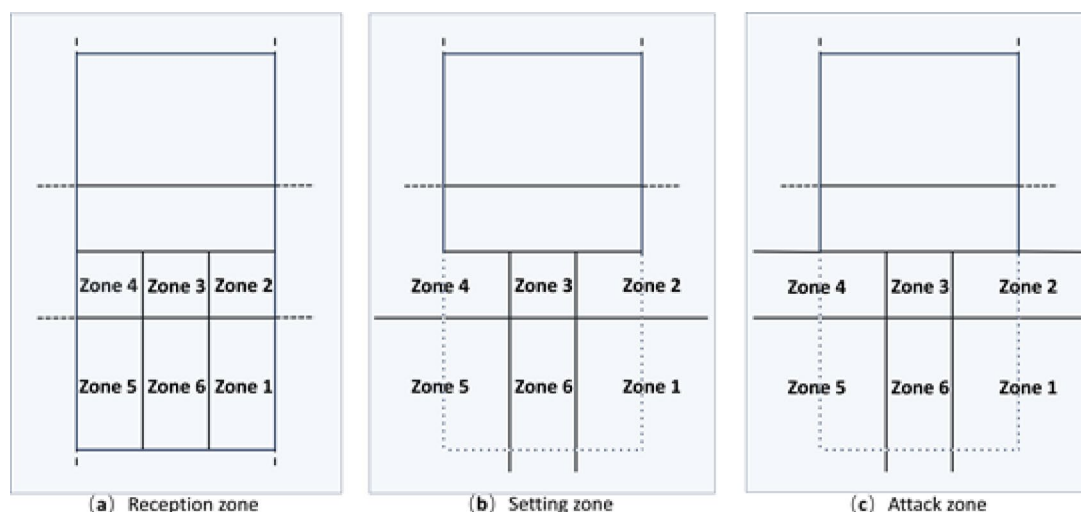


Fig. 1. Schematic diagram of zone configurations on a volleyball court.

- rules, athletes are permitted to cross the net, provided their actions do not interfere with or disrupt the opponent's gameplay. At this point, a portion of the opponent's court may be interpreted as an extension of the setting zone.
5. **Attack Tempo:** The attack tempo was classified according to the relative timing between the penultimate contact and the offensive athlete's run-up motion²⁸: (a) Fast, when the offensive athlete completes the take-off action before the contact; (b) Simultaneous, when the athlete takes one or two steps and immediately initiates the jump after contact; and (c) Slow, when the athlete takes three or more steps to prepare for the jump following contact.
 6. **Attack Zone:** The attack zone was defined as the area where the final contact or spiking action occurs. This zone mirrors the setting zone but excludes the opponent's court, as offensive athletes are prohibited from attacking in the opponent's court (Fig. 1c).
 7. **Attack Type:** The attack type was defined as the striking methods utilized during the final contact with the volleyball. Based on Costa et al.²⁹, attack types were classified into three categories: (a) Strong attack, aimed at penetrating the opponent's defense with a high-velocity strike; (b) Placed attack, targeting weak defensive areas through precise trajectory control; and (c) Tip, a soft strike at a middle to lower position of ball designed to bypass blockers and drop into vulnerable defensive zones.
8. **Block:** The blocks were classified by the specific number of athletes involved in the blocking process: (a) No-block: no athletes participate; (b) Individual block: a single athlete is engaged; (c) Double block: two athletes collaborate; and (d) Triple block: three athletes cooperate.
 9. **Attack Outcome Category:** The attack outcome category was classified based on the outcome of the offensive play⁹. (a) Point: The offensive athlete strikes the ball legally, yielding a point for the attacking team. (b) Error: A failure to strike the ball legally, resulting in a score for the defending team. (c) Continuation: The ball crosses the net or is blocked, allowing the rally to persist.
 10. **Round:** A round was defined as the phase comprising a sequence of a team's defensive and offensive actions, commencing with the first legal contact and concluding with the final one. The round model (Fig. 2) depicts ball trajectories using solid lines for mandatory paths and dashed arrows for alternative directions. Unlike traditional models where sequences strictly alternate between teams (A→B→A→B.), this model accommodates diverse sequences (e.g., A→B→A., A→B→B.). In Rounds 1 and 2, participation is restricted to serving and receiving teams, whereas subsequent rounds may involve either team. If the volleyball successfully passes the blockers, the dominant team in the following round transitions; if blocked, the dominant team remains unchanged. The model concludes when one team wins the rally.

Data collection and recording were performed by two observers, each with over five years of experience in data processing. Reliability was evaluated using Cohen's kappa coefficient³⁰ based on 10% of the observed data³¹. The Cohen's kappa coefficient for all variables surpassed 0.6, confirming exceptional inter-observer reliability.

Before analysis, input errors and missing values were detected and rectified. As shown in Fig. 3, Round 5 and subsequent rounds were rare, constituting less than 5% of the total data. While these rounds are typically regarded as low-probability events in previous studies, they still capture distinctive characteristics of extended rallies. Consequently, samples beyond Round 4 were consolidated with Round 5 for analysis.

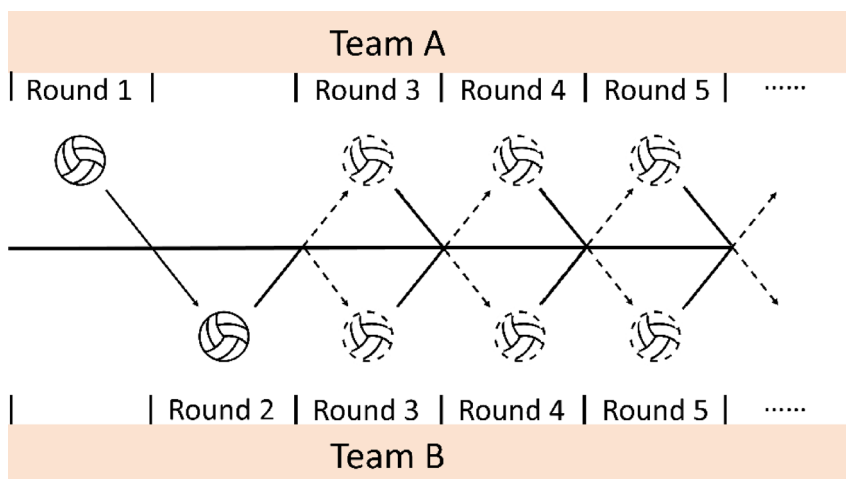


Fig. 2. Schematic model of the volleyball round system.

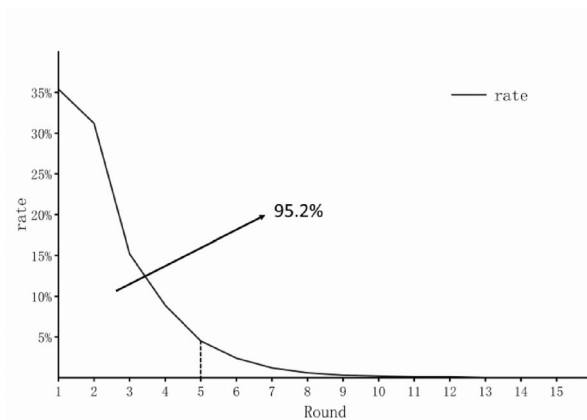


Fig. 3. Line chart representing the proportion of each round in the dataset.

Coding procedure

Data collection and primary coding were conducted by a sport-science researcher with > 5 years of experience in match-data analysis, following a predefined codebook with explicit operational definitions. Inter-observer reliability was evaluated on a randomly selected 10% subsample using Cohen's kappa³². The subsample was coded independently by a high-school volleyball coach with > 6 years of coaching and officiating experience. For the reliability assessment, the primary and independent coders worked in separate files and were blinded to each other's codes; no discussion occurred until subsample coding was completed and kappa was calculated from the two unharmonized files. Kappa values for all categorical variables exceeded 0.60, indicating substantial agreement. After reliability estimation, discrepant cases were reviewed with support from a second sport-science researcher (> 3 years of match-data processing experience) and resolved by consensus; the final dataset reflects these consensus codes.

Prior to analysis, the dataset was screened for entry errors and missing values using logical consistency checks aligned with the round definitions and variable dependencies (e.g., non-serve fields recorded in Round 1; attack type recorded without the corresponding attack zone when both should co-occur). Flagged cases were corrected by re-checking the original videos. When information could not be verified reliably (e.g., occluded views preventing zone classification), the affected fields were coded as missing and handled according to analysis requirements (complete-case analyses when all predictors were required).

Data analysis

The primary aim of this study was to ascertain whether differences in athletes' technical performance exist in various rounds. Descriptive statistical analysis was employed to explore the distribution of variables in different rounds. Subsequently, inferential statistical techniques were utilized to evaluate the relationships between each variable and the round. Serve type and serve zone were excluded from this analysis as they are only applicable to Round 1. Inferential analysis was conducted using contingency tables, chi-square tests, and Cramer's V coefficient to evaluate variable differences between rounds and the strength of the association between each variable and round. Statistical significance was set at $p < 0.05$. Cramer's V³³ was categorized as follows: weak (< 0.07), moderate (> 0.07), strong (> 0.21), and very strong (> 0.35). To identify specific differences of variables in rounds, a Bonferroni correction was applied to post hoc tests, ensuring the same significance level.

Multiple logistic regression models were employed to investigate the impact of technical performance on attack outcome category in various rounds. Attack outcome category, the dependent variable, was categorized into three groups: point, error, and continuation, with error serving as the reference category. Independent variables included serve type, serve zone, reception zone, setting zone, attack tempo, attack zone, attack type, and block. Odds ratios (ORs) and 95% confidence intervals (CIs) were computed to identify variables most strongly associated with attack outcome category and to examine their distinct influences on attack outcome categories. All statistical procedures were conducted using IBM SPSS Statistics version 24.

Result

Inferential statistical analysis in rounds

The results of the chi-square analysis are displayed in Table 1. Given that all variables accounted for over 1% in all rounds, none were excluded from the analysis. With the exception of attack type, most variables demonstrated significant correlations with the round. Notably, the reception zone and attack outcome category exhibited relatively strong correlations with the round, while the setting zone and attack tempo showed moderate associations. Both attack zone and block were significantly correlated with the round, albeit with weak association strength. As attack type failed to show a significant correlation, it was excluded from the logistic regression analysis.

Following the Bonferroni correction, distinct clusters were discerned within each variable, reflecting their associations with specific rounds. The proportions of the reception zones in Zones 1, 2, and 3 were significantly

Variable	Category	Round				
		Round1	Round2	Round3	Round4	Round5
Serve type	Power jump serve	161(4.9)				
	Jump-float serve	2910(89.5)				
	Standing serve	182(5.6)				
Serve zone	Zone 1	1698(52.2)				
	Zone 5	878(27)				
	Zone 6	677(20.8)				
Reception zone	Zone 1		440(15.8) ^a	249(20.4) ^b	147(20.2) ^b	160(20.8) ^b
	Zone 2		14(0.5) ^a	118(9.7) ^b	66(9.1) ^b	88(11.4) ^b
	Zone 3		26(0.9) ^a	136(11.2) ^b	89(12.2) ^b	93(12.1) ^b
	Zone 4		16(0.6) ^a	108(8.9) ^b	96(13.2) ^c	91(11.8) ^{b,c}
	Zone 5		1248(44.8) ^a	268(22) ^b	144(19.8) ^b	144(18.7) ^b
	Zone 6		1040(37.4) ^a	340(27.9) ^b	187(25.7) ^b	195(25.3) ^b
				$\chi^2 = 1091.888, p = 0.001^{***}, \text{Cramer's } V = 0.257$		
Setting zone	Zone 1		149(5.7) ^a	124(11.4) ^b	42(6.2) ^a	52(7.5) ^a
	Zone 2		673(25.7) ^a	214(19.7) ^b	155(23) ^{a,b}	160(23) ^{a,b}
	Zone 3		1340(51.2) ^a	413(38.1) ^b	306(45.5) ^c	295(42.4) ^{b,c}
	Zone 4		160(6.1) ^a	83(7.7) ^a	40(5.9) ^a	48(6.9) ^a
	Zone 5		71(2.7) ^a	72(6.6) ^b	46(6.8) ^b	34(4.9) ^b
	Zone 6		222(8.5) ^a	178(16.4) ^b	84(12.5) ^b	107(15.4) ^b
				$\chi^2 = 173.998, p = 0.001^{***}, \text{Cramer's } V = 0.107$		
Attack tempo	Fast		706(27.6) ^a	131(12.6) ^b	115(17.9) ^c	98(14.6) ^{b,c}
	Simultaneous		1013(39.6) ^a	310(29.8) ^b	211(32.9) ^{b,c}	246(36.6) ^{a,c}
	Slow		842(32.9) ^a	600(57.6) ^b	316(49.2) ^c	329(48.9) ^c
				$\chi^2 = 249.06, p = 0.001^{***}, \text{Cramer's } V = 0.159$		
Attack zone	Zone 1		150(5.8) ^a	82(7.2) ^a	59(8.4) ^a	59(8.2) ^a
	Zone 2		721(27.8) ^a	250(21.9) ^b	168(23.9) ^{a,b}	170(23.5) ^{a,b}
	Zone 3		329(12.7) ^a	135(11.8) ^{a,b}	85(12.1) ^{a,b}	60(8.3) ^b
	Zone 4		1227(47.3) ^a	553(48.4) ^a	304(43.2) ^a	337(46.6) ^a
	Zone 5		35(1.3) ^a	11(1) ^a	7(1) ^a	12(1.7) ^a
	Zone 6		133(5.1) ^a	111(9.7) ^b	80(11.4) ^b	85(11.8) ^b
				$\chi^2 = 90.332, p = 0.001^{***}, \text{Cramer's } V = 0.076$		
Attack type	Strong attack		1026(39.6)	429(37.6)	282(40.2)	287(39.7)
	Placed attack		1316(50.8)	572(50.2)	341(48.6)	355(49.1)
	Tip		249(9.6)	139(12.2)	79(11.3)	81(11.2)
				$\chi^2 = 7.383, p = 0.287, \text{Cramer's } V = 0.027$		
Block	No-block		126(4.9) ^a	110(9.6) ^b	55(7.8) ^b	65(9) ^b
	Individual block		749(28.8) ^a	229(20.1) ^b	176(25) ^{a,b}	180(24.8) ^{a,b}
	Double block		1687(65) ^a	787(69) ^a	467(66.4) ^a	466(64.3) ^a
	Triple block		35(1.3) ^a	15(1.3) ^a	5(0.7) ^a	14(1.9) ^a
				$\chi^2 = 64.12, p = 0.001^{***}, \text{Cramer's } V = 0.064$		
Attack outcome category	Point	154(4.7) ^a	1092(39.2) ^b	377(29.1) ^c	288(37.4) ^b	288(35.6) ^b
	Error	237(7.3) ^a	375(13.5) ^b	189(14.6) ^b	114(14.8) ^b	126(15.6) ^b
	Continuation	2862(88) ^a	1317(47.3) ^b	731(56.4) ^c	369(47.9) ^b	394(48.8) ^b
				$\chi^2 = 1439.159, p = 0.001^{***}, \text{Cramer's } V = 0.284$		

Table 1. Descriptive data for the variables. ^a, ^b, ^c denote groups within a variable category that exhibit significant differences. *** denotes statistical significance at the 0.1% level. The numbers in parentheses represent the percentage of each category within the variable in a single round.

greater in Rounds 3, 4, and 5 than in Round 2. Zone 4 exhibited marked variation, with the highest proportion in Round 4, followed by Round 5, and the lowest in Round 2. For Zones 5 and 6, proportions in Round 3 were lower than those in Round 2, while no significant differences were observed across Rounds 3, 4, and 5.

Concerning the setting zone, Zone 1 revealed no significant differences between Rounds 2, 4, and 5, yet displayed a markedly higher proportion in Round 3. The proportion of Zone 2 was notably lower in Round 3 than in Round 2. Zone 3 exhibited substantial differences across all rounds, with Round 2 presenting the highest

proportion. The proportion of Zone 4 remained consistent across rounds, whereas Zones 5 and 6 were more predominant in Round 2 than in other rounds.

In terms of attack tempo, fast attacks predominated in Round 2, while simultaneous attacks were notably more frequent in this round compared to Rounds 3 and 4. Conversely, slow attacks were most common in Round 3, followed by Rounds 4 and 5, with the least occurrence in Round 2.

Concerning attack zones, no substantial differences were noted in the offensive proportions of Zones 1, 4, and 5 across rounds. However, Zone 2 proportions were significantly higher in Round 2 than in Round 3, and Zone 3 in Round 2 surpassed that of Round 5. Zone 6 in Round 2 exhibited the highest offensive proportion in all rounds.

Regarding blocks, the incidence of no-blocks was markedly higher in Round 2 than in subsequent rounds, while individual blocks were notably more frequent in Round 2 than in Round 3. Double and triple blocks displayed relatively stable proportions in all rounds.

Attack outcome categories varied significantly across rounds. The proportion of points was least in Round 1, followed by Round 3, with no discernible differences between Rounds 2, 4, and 5. Errors in Round 1 were significantly lower than in other rounds. Conversely, the attack outcome category of continuation peaked in Round 1, followed by Round 3, while Rounds 2, 4, and 5 showed diminished proportions of continuation.

In Round 1, the jump-float serve dominated the serving, accounting for 89.5% of all serves, while the power jump serve and standing serve each accounted for approximately 5%. More than half of the serves were initiated from Zone 1, with Zone 5 contributing marginally more than Zone 6. The majority of serve effects led to continuation, as nearly 90% of the serves enabled the opponent to sustain their offensive posture.

In Round 2, reception predominantly occurred within the backcourt, with Zones 5 and 6 comprising 44.8% and 37.4% of the total, respectively. Concerning setting zones, Zone 3 accounted for the majority of actions (51.2%), trailed by Zone 2 at 25.7%. Attack tempos exhibited a relatively even distribution, with simultaneous attacks comprising the largest proportion (39.6%). Offensive strikes were chiefly concentrated in Zones 2, 3, and 4, with Zone 4 exhibiting the highest frequency (47.3%). Backcourt zones, in contrast, collectively represented less than 6% of all spiking actions. Placed attacks dominated the offensive organization (50%), followed by strong attacks (39.6%). Blocking activity was predominantly characterized by double blocks (65%), with individual blocks making up 28.8%. Points were secured in 39.2% of offensive actions.

In Round 3, reception zones were distributed more equitably, with frontcourt zones each constituting approximately 10%, and backcourt zones around 20%. Zone 6 emerged as the most dominant area (27.9%). Setting zones were predominantly focused in Zones 2 and 3, collectively accounting for more than 55% of actions. Slow attacks prevailed (57.6%) in this round, followed by simultaneous attacks (29.8%). Spiking actions were primarily concentrated in Zones 4 (48.4%) and 2 (21.9%). Blocking strategies were predominantly characterized by double blocks (69%), with individual blocks constituting 20.1%. Continuation accounted for 56.4% of attack outcome categories, with fewer than one-third of attacks yielding points.

The technical performance in Rounds 4 and 5 exhibited striking similarities. Reception zones were predominantly situated in the backcourt (around 65%), with Zone 6 comprising the largest proportion (exceeding 25%). Frontcourt zones (Zones 2, 3, and 4) each constituted approximately 10%. Setting zones were concentrated in Zones 2 and 3 (approximately 65%), with Zone 6 following. Slow attacks dominated this round (nearly 50%), while simultaneous attacks represented 33% and fast attacks occupying the smallest proportion. Spiking actions were most prevalent in Zone 4 (exceeding 40%), followed by Zone 2 (23%) and Zone 6 (11%). Blocking patterns remained stable, with double blocks comprising nearly 65% and individual blocks around 25%. Continuation was the dominant attack outcome category (approaching 50%), with points surpassing 35%.

Multiple logistic regression analysis in rounds

The results of the multiple logistic regression analysis indicated the influence of independent variables, such as serve type, on attack outcome category in different rounds. Table 2 presents the fit statistics for the logistic regression models corresponding to each round. In Round 1, the model yielded $\chi^2 (8, N = 3253) = 32.934, p <$

		Model fitting criteria		Likelihood ratio tests	
Round	Model	-2 log likelihood	Chi-square	df	Sig.
Round 1	Intercept	111.093	-	-	-
	Final	78.159	32.934	8	0.001***
Round 2	Intercept	1504.799	-	-	-
	Final	1408.018	96.78	40	0.001***
Round 3	Intercept	1064.458	-	-	-
	Final	1004.425	60.033	40	0.022*
Round 4	Intercept	786.296	-	-	-
	Final	736.07	50.226	40	0.129
Round 5	Intercept	900.108	-	-	-
	Final	851.904	48.204	40	0.175

Table 2. Model fitting information for each round. *, and *** denote statistical significance at the 5, and 0.1% level.

0.001; in Round 2, χ^2 (40, $N=2561$) = 96.78, $p < 0.001$; and in Round 3, χ^2 (40, $N=1037$) = 60.033, $p = 0.022$. However, the models for Round 4 (χ^2 [40, $N=641$] = 50.226, $p = 0.129$) and Round 5 (χ^2 [40, $N=672$] = 48.204, $p = 0.175$) failed to meet the requisite criteria for further analysis. Consequently, further analysis was restricted to Rounds 1, 2, and 3, where the models exhibited a good fit.

Table 3 illustrates that serve type emerged as a pivotal variable influencing attack outcome category in Round 1 ($\chi^2 = 31.78$, $p < 0.001$). In Round 2, both attack tempo ($\chi^2 = 19.093$, $p = 0.001$) and attack zone ($\chi^2 = 25.535$, $p = 0.004$) were found to be significant. Similarly, in Round 3, attack tempo ($\chi^2 = 9.679$, $p = 0.046$) and block ($\chi^2 = 13.179$, $p = 0.040$) significantly influenced the attack outcome category.

Table 4 presents the odds ratios (ORs) and 95% confidence intervals (CIs) for Round 1. Serve type exerted a significant influence on attack outcome category. Specifically, opting for a power jump serve rather than a standing serve in Round 1 markedly decreased the likelihood of continuation relative to errors, yielding an odds ratio of 0.201 (95% CI: 0.088–0.456).

In Round 2, the influence of attack tempo on attack outcome category is elucidated in Table 5. Playing at a fast tempo, rather than a slow tempo, significantly heightened the likelihood of points relative to errors, yielding an odds ratio of 1.765 (95% CI: 1.146–2.719).

In Round 3, Table 6 delineates key parameters, including ORs and CIs, highlighting block as a significant determinant. The likelihood of continuation was markedly higher than that of errors in no-block or individual block scenarios, relative to triple blocks. Specifically, the odds of continuation were 17.403-fold greater (95% CI: 2.201–137.637) in no-block scenarios, and 5.26-fold greater (95% CI: 1.067–25.919) in individual block scenarios, as opposed to triple blocks.

Discussion

Advantages of the proposed round model in volleyball research

This study examined technical performance across rounds using a proposed round model. Building upon the organizational structure of the traditional round system, this new framework introduces adaptations intended to better represent the role of blocking within rallies. In earlier work, Yin conceptualized rounds as alternating influences of the offensive and defensive systems of the serving and receiving teams³⁴. Within this framework, the confrontation process in volleyball was delineated into three distinct phases: the serve-and-attack phase, the receive-and-attack phase, and the stalemate phase. Subsequently, Zhu et al. advanced a round model tailored for volleyball games, emphasizing the sequential alternation of rounds between teams²¹. For instance, in Round 1, Team A serves, and in Round 2, Team B initiates a defensive counterattack. In Round 3, Team A resumes its defensive counterattack. However, under strictly alternating definitions, a blocked attack can be counted as a completed round for the defending team even when only a block contact occurs. Under indoor volleyball rules, a block contact does not count as one of the three team hits, whereas beach volleyball applies different counting conventions. In the proposed model, a block contact alone is not treated as sufficient to trigger a round transition. The new round model conceptualizes blocking as a part of a round; instead, a complete round is defined by an organized sequence that includes offensive execution after ball control. Under this framework, a blocked attack is treated as a continuation within the same team's initiative, and the subsequent re-organization is represented as the start of a new round for that team. This adjustment is intended to represent each round as a full cycle of offensive organization rather than an isolated defensive contact.

The proposed round model provides an alternative approach to dividing rounds compared with prior round definitions. The Complex model classifies phases by scenario and action chains²⁵, but it does not always preserve a fixed temporal sequence for later phases within a rally. As a result, complex-based coding can be less suitable for questions that require a consistent within-rally temporal order across extended sequences. The newly established round model effectively addresses this limitation by enabling the analysis of smaller within-rally stages in an explicitly ordered sequence. While this study focused on rounds 1 through 5, the model's adaptability allows for the inclusion of longer sequences, depending on research needs and, when needed, allowing longer sequences to be included for the analysis of extended rallies. This flexibility marks a key advantage of the new round model, enabling a more granular and comprehensive analysis of volleyball gameplay.

Round-specific variation in technical performance in elite women's volleyball

Within the framework of the newly established round model, this study examined the specific aspects of technical performance. The descriptive results indicated that athletes' choices of attack type remained largely consistent across rounds, with strong attacks constituting roughly 40%, placed attacks around 50%, and tips accounting for approximately 10%. This stability may reflect relatively consistent offensive preferences in this competition context. However, several variables (e.g., reception zone) showed statistically significant variation across rounds.

Round 1 corresponds to the serving phase within the rally structure. Serving is often described as a proactive action with relatively few constraints compared with other contacts^{7,35}, and it can shape subsequent rally conditions³⁶. In Round 1, serve type was significantly associated with attack outcome categories. Specifically, power jump serves were associated with higher odds of error outcomes. Jump-float serves are commonly observed among elite female players in international competitions⁷. Similarly, in Chinese women's volleyball, most athletes employ the jump-float or standing serve, with the power jump serve used less frequently, potentially because of higher execution demands and a greater error risk³⁷. In this study, 89.5% of serves were jump-float serves, consistent with their widespread use and comparatively low error rates reported in prior work³⁸. Players may prefer this serve type because it requires less power, can produce an unpredictable trajectory, and is associated with a lower error risk. Sex-related differences in serve speed and power reported in previous research may also contribute to differences in serve-type selection between women's and men's volleyball³⁹, which further limits the use of power jump serves. With continuation outcomes accounting for 88% of Round 1 attack outcomes, serving in this sample appeared more strongly linked to rally continuation than to direct point scoring.

Variables	Round 1			Round 2			Round 3					
	-2 log likelihood of reduced model	Chi-square	Df	Sig.	-2 log likelihood of reduced model	Chi-Square	df	Sig.	-2 Log likelihood of reduced model	Chi-square	df	Sig.
Serve type	109.939	31.78	4	0.001***	-	-	-	-	-	-	-	-
Serve zone	79.471	1.312	4	0.859	-	-	-	-	-	-	-	-
Reception zone	-	-	-	-	1415.597	7.579	10	0.67	1015.905	11.481	10	0.321
Setting zone	-	-	-	-	1421.773	13.754	10	0.184	1008.809	4.385	10	0.928
Attack tempo	-	-	-	-	1427.111	19.093	4	0.001***	1014.103	9.679	4	0.046*
Attack zone	-	-	-	-	1433.553	25.535	10	0.004**	1012.031	7.606	10	0.667
Block	-	-	-	-	1415.428	7.41	6	0.285	1017.604	13.179	6	0.04*

Table 3. Contribution of variables to prediction of attack outcome category in multinomial logistic regression. *, **, and *** denote statistical significance at the 5, 1, and 0.1% level.

Attack outcome category ^a	Variable	B	Wald χ^2 -test	Sig.	Exp(B)	95% Confidence Interval Exp (B)
Point	Serve type					
	Power jump serve	0.713	1.516	0.218	0.49	(0.157,1.525)
	Jump-float serve	0.605	1.462	0.227	0.546	(0.205,1.456)
	Standing serve ^b	0	-	-	-	-
Continuation	Serve type					
	Power jump serve	1.606	14.673	0.001***	0.201	(0.088,0.456)
	Jump-float serve	0.486	1.719	0.19	0.615	(0.298,1.272)
	Standing serve ^b	0	-	-	-	-

Table 4. Parameters estimate contrasting attack outcome category versus each other level and variable for the Round 1 ^aError is the category of references for the dependent variable; ^bCategory of references for the independent variable; *** denotes statistical significance at the 0.1% level.

Attack outcome category ^a	Variable	B	Wald χ^2 -test	Sig.	Exp(B)	95% confidence interval exp (B)
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	Jump-float serve	0.486	1.719	0.19	0.615	(0.298,1.272)
	Standing serve ^b	0	-	-	-	-

Table 5. Parameters estimate contrasting attack outcome category versus each other level and variable for the round 2. ^aError is the category of references for the dependent variable; ^bCategory of references for the independent variable; *** denotes statistical significance at the 0.1% level.

Round 2 represents the receiving team's first offensive opportunity after serve reception and, in this dataset, showed relatively favorable conditions for organized attack. Attack tempo showed the strongest association with attack outcome categories in Round 2. Previous studies on volleyball complexes have shown that the majority of attacks occur during the receiving phase and are often associated with higher scoring efficiency in complex-based analyses¹¹. Likewise, in the round model, Round 2 provides an ideal environment for offensive coordination, as the opponent's serve is relatively predictable^{40,41}. In this dataset, setting actions occurred frequently in Zones 2 and 3, which are commonly used areas for organizing attacks. In the round model, the peak proportions of Zones 2 and 3 during Round 2 may support more stable attack organization. The attack tempo in Round 2 tends to be faster, with slow-tempo attacks accounting for less than one-third of total attacks. This corresponds with previous findings indicating that receiving teams typically exhibit higher offensive speeds during the receive-and-attack phase²³. Within the sample, 27.6% of attacks in Round 2 employed fast tempos, challenging the defense and enhancing scoring potential. The regression results indicated that fast-tempo attacks were associated with higher odds of a point outcome (vs. error), with an odds ratio of 1.765. The offensive focus in Round 2 was concentrated in the frontcourt, with 66.3% of plays encountering multiple blockers—slightly lower than in other rounds. These findings highlight the practical value of Round 2 execution: maintaining reception quality and enabling faster tempos may be associated with improved scoring odds in side-out.

In this dataset, Round 3 was associated with less favorable attacking outcomes relative to earlier rounds. Blocking configurations showed a pronounced association with attack outcome categories in Round 3. When the offensive team is well-prepared, establishing an effective defense becomes exceedingly challenging⁴². One possible explanation is that transition situations in Round 3 may produce more out-of-system sets and more predictable attacking options. This often leads to backcourt settings that are more predictable to the opposition, thereby diminishing attack effectiveness⁴³. Notably, the proportion of attacks from Zone 2 was significantly lower in Round 3, while attacks originating from Zone 6 were higher. Attacks from Zone 6 may reflect constrained options rather than preferred tactical choices, which could increase the likelihood of facing well-formed blocks⁴⁴. Slow-tempo attacks dominated this round, surpassing the combined total of fast and simultaneous attacks, which further complicated offensive efforts against defensive blocks. The model indicated that continuation outcomes were more likely under no-block or single-block situations than under triple blocks. Overall, the combination of slower tempos, more backcourt attacks, and stronger blocks may help explain the lower attacking effectiveness observed in Round 3.

Rounds 4 and 5 accounted for 18.3% of plays, and no significant differences in variable distributions were observed between them, suggesting similar patterns. Although the regression did not identify significant predictors for attack outcome categories in Rounds 4 and 5, descriptive patterns indicated relatively fewer constraints than in Round 3: the combined incidence of fast and simultaneous attacks increased, while slow

Attack outcome category ^a	Variable	B	Wald χ^2 -test	Sig.	Exp(B)	95% confidence interval exp (B)
Point	Attack tempo					
	Fast	0.568	6.646	0.01**	1.765	(1.146,2.719)
	Simultaneous	0.256	2.125	0.145	1.291	(0.916,1.822)
	Slow ^b	0	-	-	-	-
	Attack zone					
	Zone 1	0.082	0.048	0.827	0.921	(0.442,1.922)
	Zone 2	0.352	1.294	0.255	1.421	(0.776,2.605)
	Zone 3	0.232	0.403	0.526	1.261	(0.616,2.585)
	Zone 4	0.545	3.171	0.075	1.724	(0.947,3.141)
	Zone 5	0.253	0.122	0.727	0.777	(0.188,3.214)
	Zone 6 ^b	0	-	-	-	-
Continuation	Attack tempo					
	Fast	0.028	0.016	0.899	0.972	(0.632,1.495)
	Simultaneous	0.073	0.183	0.669	0.929	(0.665,1.300)
	Slow ^b	0	-	-	-	-
	Attack zone					
	Zone 1	0.192	0.279	0.598	0.825	(0.404,1.684)
	Zone 2	0.12	0.158	0.691	1.128	(0.623,2.044)
	Zone 3	0.476	1.748	0.186	1.61	(0.795,3.262)
	Zone 4	0.217	0.523	0.47	1.242	(0.690,2.235)
	Zone 5	0.539	0.742	0.389	1.714	(0.503,5.846)
	Zone 6 ^b	0	-	-	-	-

Table 6. Parameters estimate contrasting attack outcome category versus each other level and variable for the round 3. ^aError is the category of references for the dependent variable; ^bCategory of references for the independent variable; ** denotes statistical significance at the 1% level.

attacks decreased. Attack outcomes also appeared improved compared with Round 3 (higher point probability and lower continuation rates), but remained slightly below Round 2. These descriptive patterns suggest that maintaining offensive readiness in later rounds may be beneficial; however, inference is limited by the relatively small sample size for extended rallies.

Practical implications and limitations

From an applied perspective, coaches may prioritize (i) Round 1 serve selection to balance pressure and error risk; (ii) Round 2 reception-to-attack organization to enable faster tempos; and (iii) Round 3 transition preparation (coverage and counterattack options) to mitigate predictable backcourt attacks and well-formed blocks.

A key limitation is that the sample was restricted to a single competition context (the 2023/2024 China Women's Volleyball Super League), which may constrain the transferability of the observed round-specific patterns to other leagues, playing styles, and competitive levels. Notably, the proposed round model is a process-ordered match-structure and observation framework, rather than a data-fitted predictive model. The present study does not include evaluation in independent contexts/datasets; therefore, the framework validity beyond this setting—i.e., whether the same operational definitions remain reliably applicable, interpretable, and capable of producing replicable round-specific patterns—remains to be established. Future work should therefore prioritize cross-context applications using independent datasets (e.g., other seasons/leagues, international competitions, and men's and youth/U-level matches) to delineate the framework's applicability boundaries and strengthen confidence in its practical use.

Conclusions

The proposed round model provides an adaptable framework for analyzing technical performance across within-rally rounds in volleyball. This study identified statistically significant variation in technical performance across rounds, indicating that action patterns differ by round. The findings indicate that associations between technical variables and attack outcome categories (point, continuation, error) differed by round. In Round 1, jump-float serves were most frequently observed, with Zone 1 as the most common serve zone. In Round 1, serve type was the only variable significantly associated with attack outcome categories, and power jump serves were associated with higher odds of errors. In this dataset, Round 2 showed relatively favorable conditions for organized offense, characterized by frequent setting actions in Zones 2 and 3, comparatively faster attack tempos, and a higher proportion of frontcourt attacks; attack tempo showed the strongest association with attack outcome categories in this round. In this dataset, Round 3 was associated with less favorable attacking outcomes relative to earlier rounds, with a greater proportion of backcourt receptions and backcourt attacking sequences; this round showed comparatively slower attack tempos and a higher frequency of multi-block situations, and blocking configurations showed the strongest association with attack outcome categories. Rounds 4 and

5 exhibited similar technical-performance distributions, suggesting comparable patterns in later rounds, and attack outcome distributions in these rounds were statistically comparable to those in Round 2.

Data availability

Data is provided within the manuscript or supplementary information files.

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Author contributions

Y.S., Q.Y. wrote the main manuscript text. Y.S., M.L. prepared all figures and tables. M.L. prepared results and conclusions. All authors reviewed the manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

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