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Technical-Tactical Analysis of Serving Strategies in Elite Women's Volleyball: Insights from the Santiago 2023 Pan American Games

Guillermo Laclote-Gutierrez [1], Jairo Azócar-Gallardo [1,2,*], Tiago Vera-Assaoka [1,2], Mauricio Cresp-Barria [3], Exal Garcia-Carrillo [1,4], Víctor Campos-Uribe [5], Eduardo Báez-San Martín [6,7] and Alex Ojeda-Aravena [1,2]

1 Departamento de Ciencias de la Actividad Física, Universidad de Los Lagos, Osorno 5290000, Chile; guillermo.laclote@ulagos.cl (G.L.-G.); tiago.vera@ulagos.cl (T.V.-A.); exal.garcia@gmail.com (E.G.-C.); alex.ojeda@ulagos.cl (A.O.-A.)
2 Programa de Investigación en Deporte, Sociedad y Buen Vivir (DSBv), Universidad de Los Lagos, Osorno 5290000, Chile
3 Department of Innovation and Education, Faculty of Education, Catholic University of Temuco Chile, Santiago 4780000, Chile; mcresp@uct.cl
4 School of Education, Faculty of Human Sciences, Universidad Bernardo O'Higgins, Santiago 8370993, Chile
5 Healthy Living, Physical Activity, and Sports Program, Universidad de Talca, Talca 3460000, Chile; vicampos@utalca.cl
6 Carrera de Entrenador Deportivo, Escuela de Educación, Universidad Viña del Mar, Valparaíso 2580022, Chile; eduardo.baez@upla.cl
7 Laboratorio de Evaluación y Prescripción de Ejercicio, Facultad de Ciencias de la Actividad Física y del Deporte, Universidad de Playa Ancha, Valparaíso 2340000, Chile
* Correspondence: jairo.azocar@ulagos.cl

Abstract: Despite its fundamental role in volleyball, the impact of serving on game dynamics during elite competitions remains unclear. This study aimed to examine the differences in serve types, directions, and outcomes of the 2023 Pan American Games. Using a quantitative cross-sectional approach with a non-experimental descriptive design, we analyzed serve types, directions, and outcomes across multiple matches. Direct observation, supplemented with advanced video analysis software, facilitated accurate data collection using observational methodology. The results revealed that 81.716% of the servers were floating servers, and 18.284% were power servers. Zone 1 (38.806%) was the primary origin, followed by Zones 6 (33.022%) and 5 (27.985%). Regarding destinations, Zone 6 had the highest proportion of serves (41.231%). Significant differences in serving effectiveness emerged between teams ($\chi^2 = 50.318$, $p < 0.001$), with 57.553% of receptions classified as "in-system" and 17.208% resulting in direct points. Power servers were associated with a higher immediate scoring rate ($\chi^2 = 8.532$, $p = 0.003$) and a greater risk of errors. Although the origin of the serve showed no significant association with the direct-point probability, it influenced the serve direction ($\chi^2 = 33.985$, $p = 0.036$). In conclusion, the results revealed statistically significant differences with respect to serve type. Power serves led to a higher proportion of "in-system" receptions compared to float serves, and produced more direct points, although both predominantly targeted the central zones (5 and 6). In contrast, the serve's origin (right, left, or center) did not significantly influence the scoring likelihood or reception outcomes, but it did affect the choice of serve destination. These findings underscore the strategic importance of serve type in maximizing offensive effectiveness.

Keywords: volleyball; athletic performance; female; physical education and training

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1. Introduction

Volleyball is one of the most popular team sports worldwide [1,2]. The results of a volleyball match largely depend on the optimal combination of cognitive and explosive movement patterns, agile and reactive positioning, and technical and tactical skills [2]. Serving, attacking, and blocking are key skills that determine the outcomes of games [2]. A serve is the action of putting the ball into play from the serving zone, and it can currently be understood in two ways: to score a direct point or to control the game by sending the ball to specific areas of the opponent's court. According to the above, the serve has evolved from an action that simply starts the game to one with an offensive purpose [3,4]. However, few studies have explored the impact of serving in high-performance volleyball.

Moras et al. [5] compared serve types, velocities, and effectiveness in a high-level volleyball tournament, whereas Buscá et al. [6] analyzed the characteristics and influences of serving among beach volleyball players. The serve has evolved into a predominantly offensive action [4] and is considered a closed skill in sports, that is, self-initiated, pre-planned, under stable conditions, focusing on technique, with little to no external interference, and analyzed based on its technique, type, and impact on the game [7,8]. The serving zone, 9 m in length, is divided into three 3 m sections corresponding to defensive positions (Zones 1, 6, and 5) [9].

The role of the serve is crucial for high-performance volleyball, and changes in serve-related tactics have generated increasing interest in analyzing related variables [10,11]. Previous studies [4,10,12] have been primarily descriptive, seeking to understand serve characteristics based on factors such as age, gender, and their relationship with in-game effectiveness [13].

A detailed analysis of the technical and tactical aspects of serving, including the trajectory and its impact on opposing teams, can reveal significant differences in player performance. Consequently, studies have used technological tools, ranging from Excel spreadsheets to mobile applications and advanced software [14]. Furthermore, game analysis is essential for identifying a team's strengths and weaknesses, which are key to strategic planning and tactical development [15].

Understanding how national team squads execute serves provides valuable information for training at both developmental and competitive levels, enhancing young players' skills in this aspect of the game. This study aimed to examine the service dynamics and its effects on the effectiveness of the game during the 2023 Santiago Pan American Games Women's Volleyball tournament.

2. Methods

2.1. Design and Participants

This study employed a descriptive observational design, which allowed for the capture of behaviors in a natural setting without researcher intervention, ensuring that the data accurately reflected the game as it occurred under tournament conditions. The methodological guidelines proposed by Barreira et al. [16] and Soriano et al. [17] were adopted.

The sample consisted of four matches from the group stage of the women's volleyball tournament at the 2023 Pan American Games in Santiago, Chile. The selected teams exhibited different tactical approaches, allowing for the observation of various serving techniques and defensive responses.

In total, 13 complete sets were analyzed, resulting in the coding and analysis of 536 motor actions corresponding to the serves performed. Data collection and processing procedures were approved by the "Physical Activity Sciences Department (CODE: 0510-23)" of the Universidad de Los Lagos in accordance with the principles of the Declaration of Helsinki.

2.2. Procedures

Observational and Validated Data Collection

We gathered data through direct systematic observations during the tournament group stage. The observed variables are detailed in Table 1 and Figure 1, following Arias et al. [4], who codified variable recommendations.

Table 1. Codes for variables of female volleyball players.

Variables Study	Description Variables
Serving Technique	Powerful Jump Serve: A serve executed overhead, a spin power serve. Floating Jump Serve: A serve delivered floating, without spin, over the head.
Serve Location	Zone 1: Serve executed from a three-meter-wide area along the right sideline, behind the baseline. Zone 6: Serve from the center, three meters from the sideline, behind the baseline. Zone 5: Serve from a three-meter-wide area along the left sideline, behind the baseline.
Destination of Serve	Zone 1: Reception inside a rectangle, located in the back of the court, on the right side of the court, 3 m from the back line and 4.5 m from the right sideline, 4.5 m from zone 6, and 3 m from zone 2. Zone 2: Reception inside a rectangle, located in the front area of the court, on the right side of the court, corresponds to 3 m from zone 1, 4.5 m from the right sideline, 3 m from the center line, and 4.5 m from zone 3. Zone 3: Reception inside a rectangle, located in the front area of the court, at the center of the court, corresponds to 3 m from zone 6 and 4.5 m from zone 2, 3 m from the center line, and 4.5 m from zone 4. Zone 4: Reception inside a rectangle, located in the front area of the court, on the left side of the court, corresponds to 3 m from zone 5, 4.5 m from zone 3, 3 m from the center line, and 4.5 m from the left sideline. Zone 5: Reception inside a rectangle, located at the back of the court, on the left side of the court, corresponds to 3 m from the baseline, 4.5 m from zone 6, 3 m from zone 4, and 4.5 m from the left sideline. Zone 6: Reception inside a rectangle, located at the back of the court, at the center of the court, corresponds to 3 m from the baseline, 4.5 m from zone 1, 3 m from zone 3, and 4.5 m from zone 5.
Result of Serve	Inside the System: Reception directs the ball within the attacking zone. Outside the System: Reception directs the ball outside the attacking zone. Direct Point: Serve scores a point directly.
Serving Error	Occurs when the serve fails to land within the opponent's court or goes out of bounds.

Two volleyball experts, each with a decade of technical experience in volleyball and specialized training in performance analysis, conducted observations. They used standardized and validated tools to accurately code each observed motor action to ensure reliable data collection.

To minimize observational bias and ensure optimal game coverage, observers were strategically placed in stands on opposite sides of the court, six meters above the court level. This height was determined through extensive preliminary testing, which proved ideal for capturing both individual player actions and the overall team dynamics. This strategic placement, combined with an unobstructed view of the court, allowed for the complete, interference-free observation of all serves and subsequent gameplay actions.

In addition to direct observations, physical data on each player's attack reach were collected throughout the tournament. To complement live observations and enable more detailed post-game analysis, we implemented a high-quality recording system. Each match

was recorded using Canon EOS 80D cameras (Canon Inc., Tokyo, Japan), which are known for their high image quality and reliability in sports. The cameras were set to capture Full HD (1920 × 1080 pixels) at 60 frames per second, a high frame rate chosen to facilitate the accurate analysis of each serve, capturing quick and subtle movements. The cameras were mounted on professional tripods with stabilization systems to eliminate any vibrations or movements and ensure clear, uninterrupted footage for subsequent analysis.

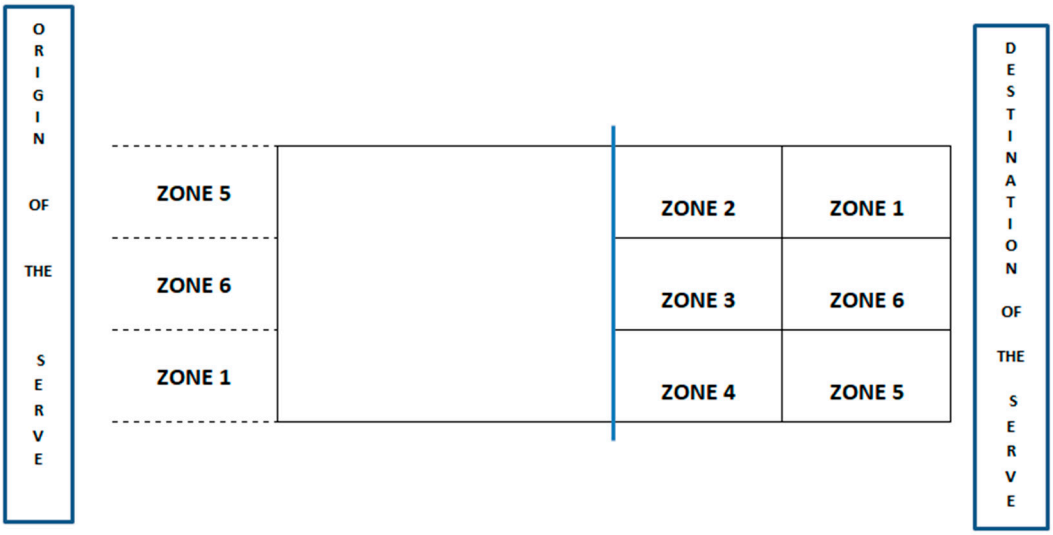


Figure 1. Origin and destination of the serve.

Following data collection, the variables were encoded into a Microsoft Excel spreadsheet by the lead author and a volleyball expert and verified using DartFish ProSuite (Dartfish SA, Friburgo, Suiza). This allowed for a thorough frame-by-frame review of each serve performed. A rigorous validation protocol was followed in which two observers independently coded the data based on predefined criteria and resolved discrepancies through consensus. Cohen's Kappa coefficient, with a minimum threshold of 0.80, was used to ensure inter-observer reliability. In cases of significant discrepancies, a joint review of the video recordings was conducted to achieve final consensus.

3. Statistical Analysis

The dataset was initially organized using Microsoft Excel and analyzed using JASP statistical software (JASP Team, 2023, Version 0.17). To describe the dynamics related to the service, descriptive analyses included absolute and percentage frequencies using contingency tables. Differences between variables according to technical actions and their relationship with their effectiveness were analyzed using the chi-squared test (χ^2). The strength of the associations identified as effect sizes was quantified using Cramer's V. Statistical significance was set at $p < 0.05$.

4. Results

4.1. Analysis by Type of Serve

4.1.1. Serve Type and Reception

Of the 451 reception outcomes, there was a small yet statistically significant association ($\chi^2 = 7.96$, $p = 0.019$, ES = 0.133) between serve type and reception outcome. For power serves, most receptions (77.0% out of 74) occur "in-system". Another 17.6% result in "out-of-system" receptions, and 5.4% lead to a "ball return". In contrast, float serves also showed a majority of in-system receptions (68.7% out of 377) but exhibited a higher proportion of

out-of-system receptions (29.7%) and a lower incidence of returns (1.6%) when compared to power serves.

4.1.2. Serve Type and Destination

Of the 536 serving actions analyzed, 18.3% (n = 98) were power serves and 81.7% (n = 438) were float serves. Statistical testing of the relationship between serve type and destination (1, 2, 3, 4, 5, 6, 7, and 8) indicated significant differences (χ^2 = 16.569, p = 0.020, ES = 0.176). A closer look at the distribution reveals that the float serves primarily target Zones 5 (22.9% of the total) and 6 (31.2%), which together account for approximately 66% of all float serves. The power is concentrated mainly in Zones 5 (3.5%) and 6 (10.1%), which together comprise approximately 74% of the servers. Although the remaining destinations (1, 2, 3, 4, 7, and 8) have lower frequencies, Zones 7 (1.7%) and 8 (1.3%) are relatively more prominent when serving with power compared to the float.

4.1.3. Serve Type and Direct Points

Of the 536 serving actions, 3.358% (18 serves) resulted in a direct point, with statistically significant differences according to serve type (χ^2 = 8.532; p = 0.003, ES = 0.126). Among the power servers, 8.2% (8/98) produced direct points, whereas only 2.3% (10/438) of float servers produced direct points.

4.2. Analysis by Serve Origin

4.2.1. Origin and Direct Points

From a total of 536 serving actions, 3.358% (n = 18) resulted in direct points distributed almost uniformly among the three origins considered (right, left, and center of the court). Statistical analysis (χ^2 = 0.415, p = 0.813, ES = 0.028) indicated no significant difference in the likelihood of scoring a direct point based on the serve origin. Specifically, serves from the right accounted for 1.306% of the total direct points (7/536), serves from the left for 0.746% (4/536), and serves from the center for 1.306% (7/536).

4.2.2. Origin and Ball Destination

From the 536 serving actions analyzed, the cross-tabulation of origin (right, left, and center of the court) and destination (1, 2, 3, 4, 5, 6, 7, and 8) revealed statistically significant differences (χ^2 = 31.770, p = 0.004, ES = 0.172). Overall, the right, left, and center origins represented 38.99%, 27.99%, and 33.02% of the total actions, respectively, whereas Zones 5 and 6 received the most serves (26.49% and 41.23%, respectively).

However, distinct distribution patterns exist based on their origin. For the right origin (209 serves, 38.99% of the total), most serves were directed to Zones 6 (15.67% of total actions) and 5 (13.62%), with fewer serves directed to other zones. For the left origin (150 serves, 27.99%), most serves were directed to Zones 6 (11.01%) and 5 (6.34%), and there was an increase in serves in Zone 8 (3.17%) compared with the right origin. For the center origin (177 serves, 33.02%), Zones 6 (14.55%) and 5 (6.53%) were primarily targeted, but there was a slight increase in serves to Zone 7 (2.80%) and a somewhat higher proportion of serves to Zone 4 (1.12%) than the other origins.

4.2.3. Origin and Ball Reception

Of the 451 reception outcomes recorded, the cross-tabulation of origin (right, left, center) and reception outcomes (in-system, out-of-system, ball return) showed no statistically significant differences (χ^2 = 5.754, p = 0.218, ES = 0.080). Generally, the right, left, and center origins accounted for 41.37%, 25.66%, and 32.96% of all serves, respectively. Meanwhile, in-system receptions were predominant (70.13% of total serves), followed by out-of-system receptions (27.65%), and, to a lesser extent, ball returns (2.21%).

Although the right origin showed a slight predominance of in-system receptions (29.43% of all servers), the left origin presented a marginally higher proportion of ball returns (1.11%) and the center origin showed an intermediate distribution among these categories. However, these variations were not statistically significant.

5. Discussion

This study aimed to examine serve dynamics and their effects on the effectiveness of the game during the 2023 Santiago Pan American Games Women's Volleyball tournament. Overall, the findings from this study indicate that, although both float serves and power serves tend to generate a high frequency of in-system receptions, float serves are associated with a greater number of out-of-system receptions, whereas power serves yield a slightly higher proportion of returns. Moreover, both serve types primarily target sectors 5 and 6, although differences in their distribution are statistically significant with a small-to-moderate effect size. Regarding the probability of achieving a direct point, power servers demonstrated greater effectiveness than float servers, reinforcing their impact on performance. In contrast, the serve's point of origin (right, left, or center) does not appear to exert a significant influence on the attainment of direct points or reception outcomes; however, it differentially affects the selection of the destination, particularly for zones other than 5 and 6, which account for most deliveries.

The results indicated that jump float serves were the most frequently used, accounting for 81.716% of the executions, whereas power jump serves were used in 18.284% of the cases. These results suggest an evolution in serving strategies that influences overall game performance. They also highlighted the variety of serves employed by teams, reflecting a trend toward tactics that balance offensive and tactical aspects, particularly regarding jump float serves. According to Quiroga et al. [3] (2010), who analyzed 1300 serves in the European Women's League, 59% were standing serves, 17% were jump float serves, and 24% were power jump serves, thus demonstrating a definitive shift toward jump serves in women's volleyball.

This preference for jump serves (float and power) in elite women's volleyball approaches the patterns observed in high-level men's volleyball. For example, Valhondo-Estévez et al. [18] reported that top-level European male players used a power jump 57.7% of the time to disrupt their opponent's attack setup. Lirola [19] found that, in men's high-performance volleyball, 76.2% of players employed power jump serves and 20.6% used jump float serves, with almost no use of standing float serves. Similarly, Ciuffarella et al. [20] noted that 69.9% of male players in the Italian league allocated 69.9% to power jump serves and 26.9% to jump float serves. Although power jumps and serves can increase the reception difficulty, they must be used strategically because of their higher error rates. Similar trends were observed in the Men's World Cup, where 76.3% of serves were power jump serves and 23.7% were jump float serves. This study suggests that serving strategies are influenced by the opponent's quality and match circumstances, improving volleyball performance when adjusted accordingly [21].

When examining serves across different male age groups in the Spanish league, varied usage patterns emerged: in the U14 category, 16.4% were jump float serves and 1.47% were power jump serves; in U16, 40.5% were jump float serves and 8.2% were power jump serves; and in U19, 51% performed jump float serves and 11% used power jump serves. At the international level, the trend shifts: 69% of serves are power jump serves and 29% are jump floats [22].

In terms of serve origin in our study, Zone 1 was the most frequently used (38.806%), followed by Zone 6 (33.022%) and Zone 5 (27.985%). These findings align with those of Valhondo-Estévez et al. [18] in men's competitive volleyball, where 47.4% of serves

originated from Zone 1, producing diagonal trajectories that forced forearm receptions. These parameters should be considered when planning training. Quiroga et al. (2010) [3] likewise found that high-level European female players predominantly served from Zone 1 (60%). However, this contrasts with Portela-Pozo et al. [23], who found that Zone 6 was preferred (42.1%) for complicated receptions in university-level volleyball.

Regarding serve destination, our data indicated that most serves targeted Zone 6 (41.231%), followed by Zone 5 (26.493%) and Zone 1 (14.552%). These findings are consistent with those of Valhondo-Estévez et al. [18] for European volleyball teams, who noted that 40.8% of the serves were directed toward Zone 6, creating medium diagonal trajectories. Gil Arias et al. [9] also reported similar outcomes in Spanish youth players, suggesting that the increasing use of jump serves brings youth training closer to elite profiles. Consequently, servers were executed more tactically to direct the ball away from the setter. Nevertheless, serving strategies in developmental categories must be adapted to players' characteristics and level of play.

Concerning serve outcomes, our study revealed that 58.995% resulted in "in-system" receptions, 23.321% in "out-of-system," receptions, and 15.485% led to direct points. The latter figure is higher than that reported by Marzano-Felisatti [10]. They reported that U20 (7%) and U18 (9%) for female players, suggesting an increase in serving effectiveness as the competition level increased. It also surpasses the 10.3% of direct-point serves reported by Gil Arias et al. (2011) [4] in Spain's men's youth Super League and 8.4% reported in the 2007 Men's World Cup Marcelino et al. [21]. These results imply that in unfavorable situations, volleyball teams tend to choose higher-risk serves, whereas in balanced contexts, they opt for more conservative tactical decisions, regardless of whether they have an advantage.

Concerning direct-point serve efficiency in men's volleyball, different age categories showed varying trends: U14 = 11.6%, U16 = 7.3%, U19 = 4.3%, national adult level = 3.15%, and international teams = 3.05%. This indicates that higher competition levels lead to a greater risk of serving, thereby increasing the margin of error [22]. However, Valhondo-Estévez et al. [18] analyzed 3292 serving actions among 16 adult men's European Championship teams and reported 47.2% effectiveness, underscoring the role of technical and tactical factors at the elite level.

These findings emphasize the importance of research that is specific to sex and level of competition and serves to inform training programs and match strategies.

Despite the significance of these findings, this study had limitations. It focused on the group stage, which may not fully represent the strategies used in the later phases of a tournament. Moreover, there was no comparative analysis between qualifying and non-qualifying teams, nor was there a breakdown of players' positions in this study. Another limitation is the absence of contextualization with other game variables such as the opponent's reception or subsequent attack strategy. Future research should address these limitations to provide deeper insights into strategies for serving elite women's volleyball players.

Nonetheless, this study had several strengths. It focuses specifically on elite women's volleyball, a less explored area than that of men's volleyball. Its comprehensive analysis of serving, encompassing multiple variables (type, origin, destination, and outcome), provides a holistic perspective of this key game action. Rigorous observational methodology, including the use of specialized software such as DartFish ProSuite, ensures high precision in data collection. Furthermore, a substantial sample of 534 serves and robust statistical analysis provides a solid foundation for the conclusions drawn. The context of the Pan American Games adds valuable information about performance in major international tournaments.

It is also important to consider that this study analyzed regional tournaments. Therefore, future studies should focus on analyzing Olympic Games to contrast our results. We also recognize that we analyzed a limited number of games; therefore, a larger volume of games should be considered in future studies. In addition, comparisons with previous studies help identify trends and evolutions in serving strategies, while a detailed analysis of team differences offers practical information for coaches and analysts.

In practical terms, this study provides a comprehensive and detailed overview of the impact of serving tactics in elite volleyball, emphasizing the high prevalence of float serves and the significant strategic role of power serves. The findings suggest that although float serves dominate because of their high likelihood of keeping play "in-system," power serves, albeit less frequently, have a critical impact on the game by substantially increasing the odds of scoring directly and disrupting the opposing team's reception. This study underscores the importance of adapting and diversifying serving strategies to effectively exploit opponents' weaknesses and maximize the serving team's performance. Moreover, the results indicate that the choice of serve origin influences the serve direction, although not necessarily the likelihood of achieving direct points. This opens up new lines of inquiry into serving tactics and strategies in competitive volleyball. These findings not only enrich the academic understanding of volleyball, but also provide practical guidance for coaches and players aiming to optimize their serving techniques in competitive contexts.

6. Conclusions

The results revealed statistically significant differences with respect to serve type. Power serves lead to a higher proportion of "in-system" receptions compared to float serves, and produce more direct points, although both predominantly target the central zones (5 and 6). In contrast, the serve's origin (right, left, or center) did not significantly influence the scoring likelihood or reception outcomes, but it did affect the choice of serve destination. These findings underscore the strategic importance of serve type in maximizing offensive effectiveness.

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Informed Consent Statement: Informed consent was obtained from all participants.

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Conflicts of Interest: The authors declare no conflict of interest.

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