ORIGINAL ARTICLE

Optimal serve distance for greater ball flight deviation in volleyball float serves

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ABSTRACT

In volleyball, the float serve is used to create aerodynamic instabilities that will cause deviations from the normal parabolic trajectory. Previous studies have examined serve speed and ball aerodynamics, but the relationship between serve flight distance and trajectory deviation remains unknown. Using a dual camera system, standing float serves were recorded in real conditions. Serves were executed from 9-13m before the net aiming at 3-9 m beyond the net, generating 1224 different serve trajectories. Early frame prediction of landing coordinates for each serve was compared with the real landing coordinates to quantify deviations from the expected parabolic trajectory. Prediction errors were analysed for their dependence on the serve distances with the ANOVA procedure, and the found optimal distances were associated with the increased expectation of achieving high deviations (≥27.1cm) with the Fisher's exact test. Results showed that 16-17 m is associated with increased trajectory deviation when compared to shorter ($p < .001$) and longer ($p < .001$) distances. Optimal distance serves were 28% more likely to achieve high deviations. This study shows that the serve distance can be used as a simple, equipment-free coaching tool to achieve trajectory deviation of a float serve in training and in a match.
Keywords: performance analysis, coaching, aerodynamics, sports performance, trajectory analysis.

Cite this article as:
Laios, A., Karanasiou, I., Sotiropoulos, K., Kyprianou, M., & Barzouka, K. (2026). Optimal serve distance for greater ball flight deviation in volleyball float serves. *Journal of Human Sport and Exercise, 21*(4), 1443-1458. https://doi.org/10.55860/cr051k36

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Submitted for publication June 14, 2026.
Accepted for publication July 27, 2026.
Published August 19, 2026.
Journal of Human Sport and Exercise. ISSN 1988-5202.

doi: https://doi.org/10.55860/cr051k36

INTRODUCTION

In the modern indoor volleyball, the serve is a unique action. Serve is defined as the first offensive action of each rally (Masumura et al., 2007; Palao et al., 2004), while it is the only one that has autonomy. According to FIVB (2025) rule 12.4.4, the server has eight seconds to hit the ball which means that the player can hold the ball and he is not reacting or affected by a previous action (Marcelino et al., 2012). Within that eight second window the server can decide on the type, trajectory, and power of the hit (Garcia-Tormo & Vaquera, 2015; Stamm et al., 2016). Serving is the starting point of every rally, and subsequently it is used as the primary tactical tool to disrupt the opponent's reception-set-attack complex and is recognized as a critical performance factor, as it can directly lead to a point (Ascic et al., 2024; Silva et al., 2014). Due to the rotation regulation (FIVB, 2025, Rule 7.6), every player on the court (excluding the Libero) must execute this skill, making the ability to manipulate the serve's trajectory a requirement for every player, since the serve effectiveness has an impact on game outcome (Drikos, Ntzoufras & Apostolidis, 2019).

Serves can primarily be categorized by their rotational characteristics and the resulting aerodynamic forces. Players may use the spin serve that has high angular velocity. Then due to Magnus Effect a downward pressure is generated (Goff, 2013) that allows high-velocity trajectories to land within the 18m court boundaries. Alternatively, players may use the float serve. That relies on executing the hit with little or no rotation of the ball (Ascic et al., 2024), so as to cause an unpredictable change in its trajectory in flight (Logan, 2023).

In contrast to the float serve, the spin serve creates a predictable trajectory. Its flight path behaviour is described by the relationship between velocity and the Reynolds Number (Re). Mikasa V200W, which is used in our analysis, has been FIVB's official indoor ball since 2018 and differs substantially from previous models in terms of panel configuration and aerodynamic characteristics (Tamaru et al., 2021). As it travels through the air, its 18-panel 'double-dimple' surface influences the boundary layer transition, a phenomenon observed in earlier studies on honeycomb-panel balls (Asai et al., 2010). As air resistance reduces the ball's speed, it goes through a critical velocity threshold where airflow becomes unstable, resulting in sudden lateral and vertical forces that cause the ball to wobble or deviate from a standard parabolic path (Depra et al., 1998; Dumek et al., 2018; Hong et al., 2019; Hong et al., 2020).

Research has extensively examined the speed of the serve and its relationship with both athletic performance and industrial design factors, including surface patterning and panel configuration (Hong et al., 2019). It has been found that the speed of the serve varies significantly depending on the player's position, the current score of the match and the level of the competition. Additionally, higher competition levels are associated with faster execution speeds (Altundag et al., 2024). Similarly, the physical ability to generate force and force-velocity profiles are significantly related to spike and serve speed in high-level players (Baena-Raya et al., 2021). However, these studies mainly focus on speed as a final indicator of performance rather than the shape of the ball's trajectory in flight.

Likewise, other more applied analyses have shown that 'floating' the ball is an important element of serve success, as it is associated with poor reception and (Logan, 2023; Reiser et al., 2020), consequently, lower setting quality (Gonzalez-Silva et al., 2020). However, the majority of the work available focuses on two things. The effectiveness of the serve as an in-game result and the accuracy/speed of execution. Therefore, missing out the mechanism through which the ball begins to deviate from the ideal parabolic trajectory in real-world flight conditions.

In addition, modern techniques of video analysis and three-dimensional trajectory reconstruction have made it possible to study the movement of the volleyball in more detail (Alptekin, 2016; Chen & Chu, 2021; Cheng et al., 2022; Depra et al., 1998; Horiuchi et al., 2019; Kawakami et al., 2017; Reiser et al., 2020). Chen & Chu (2021) showed that 3D reconstruction of trajectories by two cameras can support advanced forms of analysis in the sport, highlighting the importance of three-dimensional information in interpreting ball flight. However, these applications have been used primarily for action recognition and tactical analysis rather than for studying the deviation from the parabolic orbit of the float serve.

Therefore, despite significant progress in the study of efficiency, speed and aerodynamics of the serve, there remains a research gap as to the relationship between the total flight distance of the ball and the occurrence of deviations from the ideal parabolic trajectory in real float serves. Exploring this gap is of value because it can bridge the theoretical understanding of the ball's aerodynamic behaviour with a directly applicable training direction. That was highlighted by Altundag et al. (2024) who concluded that targeted training interventions are necessary to optimize serving speed.

The distance between the expected and the actual ball position is related to float serve efficiency (Reiser et al., 2020). In this context, the purpose of the present study was to investigate the relationship between the execution distance of a float serve's starting point to the landing point and the occurrence of deviations from the ideal parabolic trajectory of the ball during its flight. The study was based on the analysis of real three-dimensional ball trajectories, and to determine whether flight distance can be used as a practical, externally observable coaching variable through which the aerodynamic conditions associated with float behaviour can be achieved. Based on the results of the analysis, it is hypothesized that the execution of float serve with a target total distance of about 17 m creates the right conditions for the occurrence of deviations from the parabolic orbit.

This finding can be used as a practical tool in the coaching process, offering coaches a clear direction for learning and practicing float serve with the goal of maximizing the instability of ball flight. Identifying a distance range with increased float behaviour could be used as a simple and equipment-free method of training float serves. Beyond identifying an optimal flight distance, the present study proposes a practical framework for float serve training which can easily be transferred to match conditions. Instead of attempting to estimate ball velocity or Reynolds number during practice, coaches and players may use serve flight distance. Therefore the study aims not to explain float serve aerodynamics per se but to translate this knowledge into an easily applicable coaching method.

MATERIAL AND METHODS

Experimental design

The study analysed the flight trajectories of volleyball non jump float serves, performed by a highly experienced competitive player. The purpose of the study was not to compare athletes or serving techniques, but to investigate the relationship between serve flight distance and trajectory deviation under real conditions. Therefore, data were collected by a single highly experienced player who was capable of repeatedly producing float serves with minimal or no ball spin across a wide range of flight distances. The independent variable was the ball trajectory distance and not any player-related characteristic. So the player served primarily as a mean of generating a large number of realistic launch conditions. The study aimed to sample as many combinations of serve flight distances as possible, rather than to evaluate individual serving performance. The force required to produce the investigated trajectories lies well within the physical capabilities of male, female, and junior volleyball players. Consequently, the objective was not to determine the maximum force a player could generate, but to examine how different realistic serve flight distances can influence the aerodynamic behaviour of the ball, once appropriate launch conditions have been achieved.

The float serves were executed from five serving positions located 9, 10, 11, 12 and 13 m from the net, targeting seven landing zones positioned 3-9 m beyond the net (Figure 1). For each serving position and target combination, 40 serves were recorded. All serves were performed using a Mikasa V200W volleyball, the official ball used in international competitions that is approved by the International Federation of Volleyball (FIVB). The net height was set at 2.24 m. A women's net height was used to ensure that the findings would be applicable to both male and female players. Also, the server's height (1.90 m) was representative of adult players regardless of gender so the net height does not affect the relationship between serve distance and trajectory deviation. Only serves that met the following criteria were included in the analysis: no visible ball spin, ensuring that the trajectory corresponded to a true float serve; no contact with the net; a trajectory below antenna height; unobstructed visibility in both camera views. A total of 1224 serves were recorded. After applying the inclusion criteria and excluding the serves that did not meet those criteria, 823 serves were kept for analysis. The procedures received University Ethics Committee approval (no: 1490/15-02-2023, SPESS-NKUA).

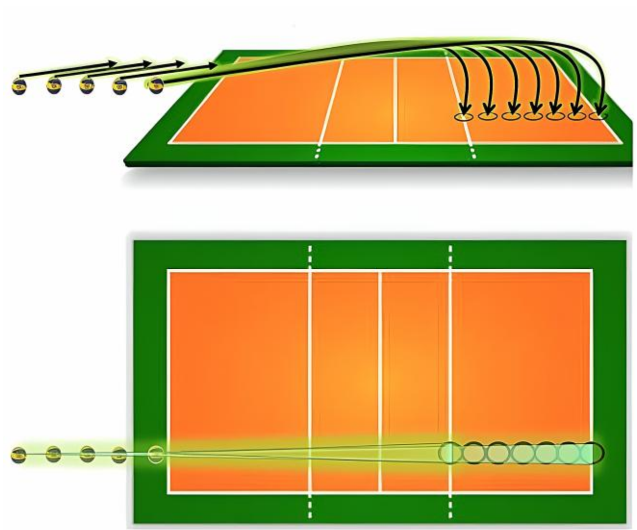

Figure 1. Experimental setup showing five serving positions and seven target landing zones.

Video recording
The ball trajectories were recorded using two DJI Osmo Action 3 cameras positioned orthogonally around the court. The cameras were placed at ground level with these specifications: lens height at 25.2 mm; focal length of 2.28 mm; resolution at 3840p x 2160p (4K); frame rate at 60 fps; field of view of 155°. One camera was positioned along the net's extension, while the second camera was placed perpendicular to the net. This orthogonal configuration enabled reconstruction of the three-dimensional trajectory of the ball from two synchronized two-dimensional image sequences.

Court calibration
To convert image coordinates to real-world coordinates, a calibration procedure was performed using known reference points on the court. A calibration pole with markers placed at heights of 0, 1, 2, and 3 m was positioned at 18 locations across the court. That produced 72 reference points distributed throughout the court volume, enabling accurate spatial reconstruction of ball trajectories across the entire flight region.

For each calibration point were recorded: (i) the real-world coordinates (X, Y, Z) and (ii) the corresponding pixel coordinates in both camera images. These calibration data were used to establish the mathematical relationship between pixel coordinates and real-world spatial coordinates.

3D Reconstruction of the ball trajectory

The theoretical relationship between image coordinates and spatial coordinates can be described using the Direct Linear Transformation (DLT) framework, which relates the position of a point in three-dimensional space to its projections in two camera views.

However, the wide field-of-view of the action cameras introduced noticeable lens distortion, which reduces the accuracy of classical DLT reconstruction.

Therefore, a regression-based calibration approach was implemented. Using the calibration dataset, regression models were constructed to estimate the three-dimensional position of the ball from the pixel coordinates observed in both cameras.

The resulting mapping can be expressed as:

$$(X, Y, Z) = F(x_s, z_s, y_b, z_b)$$

where

- x_s, z_s are pixel coordinates from the side camera
- y_b, z_b are pixel coordinates from the back camera.

To further improve accuracy across the large spatial volume of the court, the court space was subdivided into smaller spatial regions, and separate regression models were fitted for each region using nearby calibration points.

Ball tracking

For each recorded serve, the centre of the volleyball was manually identified in each frame of both camera videos. The centre corresponded to the centre of the circular outline of the ball.

The recording frame rate (60 fps) with the typical flight duration of a float serve (~1 - 1.5 sec), resulted in approximately 60-90 tracked positions per trajectory. Those provided sufficient information regarding the ball flight.

Dataset size

The experimental protocol produced a total of 823 float serves, corresponding to combinations of five serving positions and seven target areas in the opponent's court.

Each serve was recorded at 60 frames per second, resulting in approximately 60-90 frames per trajectory depending on the flight duration of the ball.

For each frame, the centre of the ball was identified in both camera views, yielding four pixel coordinates:

- x_s, z_s from the side camera
- y_b, z_b from the back camera.

Consequently, the dataset contained approximately 300,000 raw coordinate observations, which were used for three-dimensional reconstruction of the ball trajectories. This high temporal resolution allowed detailed reconstruction of ball trajectories and enabled reliable estimation of early-flight dynamics.

Trajectory modelling

After reconstruction, the ball trajectory was described using projectile motion models. The vertical component of the trajectory was approximated by a quadratic function:

$$z(t) = at^2 + bt + c$$

while the horizontal motion was approximated using linear functions:

$$x(t) = v_x t + x_0$$
$$y(t) = v_y t + y_0$$

These equations were estimated using the early portion of the recorded trajectory data. The parabolic model represents the theoretical trajectory as expected under ideal projectile motion. Therefore it is a reference framework against which deviations in the observed float-serve trajectories can be quantified. This approach allows the comparison between the theoretical projectile trajectory (the predicted one) and the experimentally observed ball flight (the real one). That enables the identification of distance-dependent deviations from the ideal parabolic motion.

Landing prediction

The predicted landing time t_{land} was determined by solving the vertical trajectory equation for the condition

$$z(t_{land}) = 0$$

The corresponding landing coordinates were then calculated using the horizontal motion equations. The predicted landing position (x_p, y_p) was compared with the actual landing position (x_a, y_a), determined from the frame corresponding to the first visible contact between the ball and the court surface.

Prediction error was calculated as

$$error = \sqrt{(x_p - x_a)^2 + (y_p - y_a)^2}$$

which represents the 2D distance between predicted and actual landing points. This error quantifies the accuracy of the trajectory-based landing prediction.

Calculations and statistical analysis

The real travelling distances were rounded to the nearest integer. Thus, a distance of 11 m denotes all serves with a real travelling distance ≥10.5 m and <11.5 m and so on. The primary outcome variable, which is the prediction error in meters was subjected to one-way analysis of variance (ANOVA) with the distance groups as calculated above.

Based on the above results, the distance groups were further categorized into three groups (Group 1: 11-15 m, Group 2: 16-17 m, Group 3: 18-22 m). These three groups were once more subjected to the ANOVA procedure with prediction error as the dependent variable.

To the purpose of providing more useful practical information, once the distance range that provides the optimal (maximum) prediction error has been determined, a binomial (dichotomous) variable with optimal versus non-optimal distances was created. Against this variable a Receiver Operating Characteristics (ROC) analysis with prediction error as the discrimination variable was performed. The purpose was, after the proof of significant discrimination ability with area under the curve (AUC) significantly greater than 0.5, to find the Youden's index, i.e. the cutoff value of prediction error that provides the best trade-off between sensitivity and specificity. The practical value of this cutoff is to provide through the odds ratio (OR) direct information on the increased expectation of maximal prediction error when the serve is directed at optimal distances.

RESULTS

The ANOVA procedure showed that the prediction error is significantly associated with the distance travelled by the volleyball (F = 17.3, df = 11,811, *p* < .001). As Figure 2 shows this association is rather complex. Starting from the minimum distance of 11 m and up to 15 m the prediction error was quite low and remained consistently below 0.21 m. However, at the distance of 16 m there was a very sharp increase of the prediction error, rising above 0.25 m. There was a further increase of the prediction error for the 17 m distance that reached almost 0.3 m. Further on, for the longer distances 18-20 m there was once again a reduction in the prediction error that remained within the 0.21-0.25 bounds.

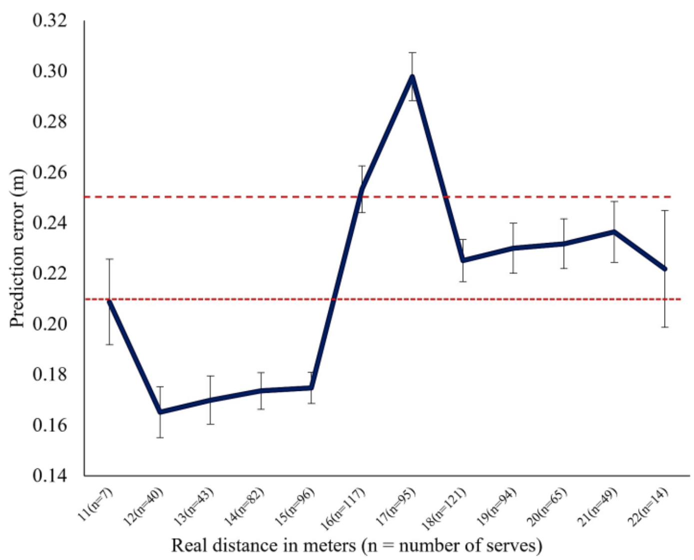

Figure 2. Mean prediction error (±SE) as a function of real serve distance. Red dashed lines indicate the thresholds used to classify low, medium, and high prediction error serves.

The ANOVA procedure was repeated using as the independent variable the three calculated distance groups (F = 85.6, df = 2,850, *p* < .001). As Figure 3 shows the optimal distance group, where the maximal prediction error can be observed is for the 16-17 m. The mean value of the prediction error for this group is significantly greater than for the shorter distances of 11-15 m (*p* < .001), but also than from the longer distances 18-20 m (*p* < .001). On their own turn, these longer distances provide significantly greater prediction errors than the shorter distances (p < .001). Serves performed over longer distances are characterized by higher initial velocities but are subject to greater aerodynamic deceleration, enabling the ball to enter the critical velocity range during flight, whereas shorter-distance serves are executed below this threshold and therefore cannot reach the conditions required for aerodynamic instability.

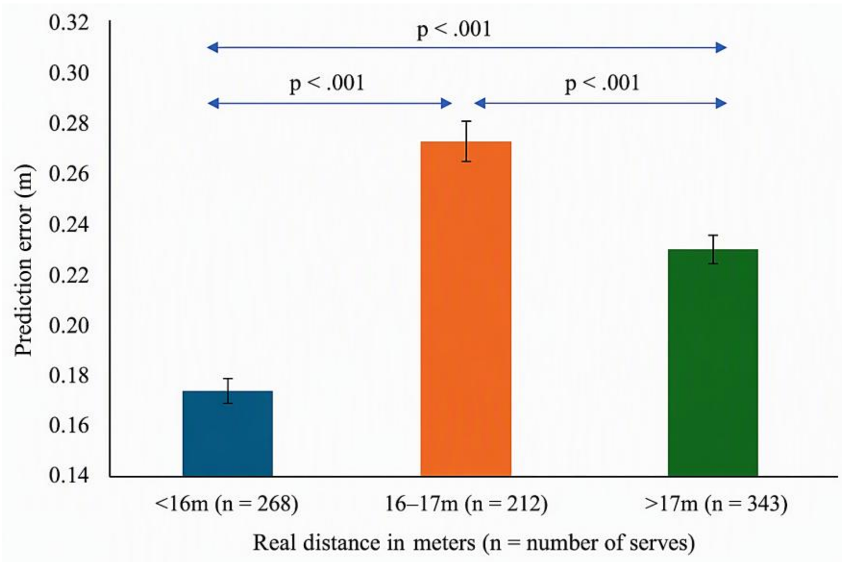

Figure 3. Mean prediction error (±SE) for the three serve distance groups and p-values for the between-group differences.

According to the above results the group distances were categorized into the binomial variable of optimal (16-17 m) versus non-optimal distances (all the other distances). Figure 4 shows the significant discrimination ability of prediction error on the optimal distance.

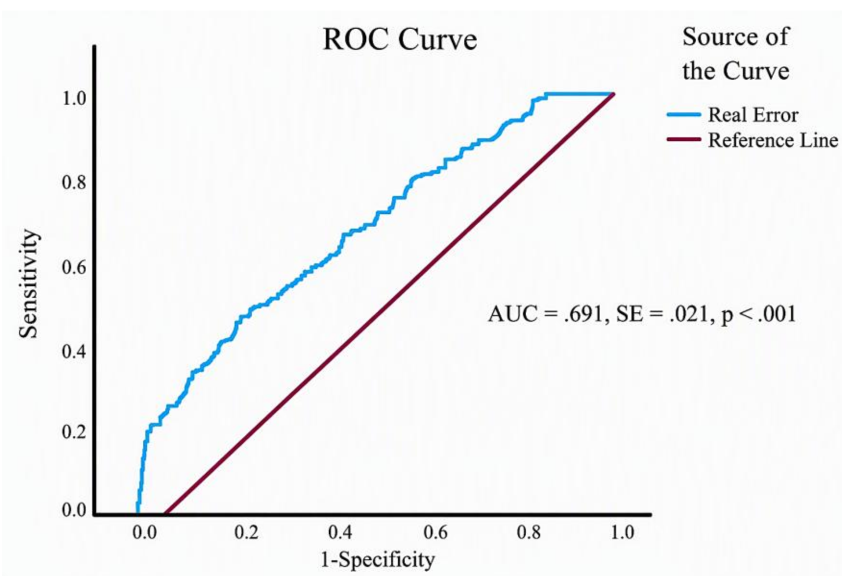

Figure 4. ROC curve showing the ability of prediction error to discriminate optimal serve distances.

Figure 5 provides the Youden's index for the prediction error on the optimal distance. This was found to be at 0.271 m, which is slightly greater than the diameter of the Mikasa V200W ball.

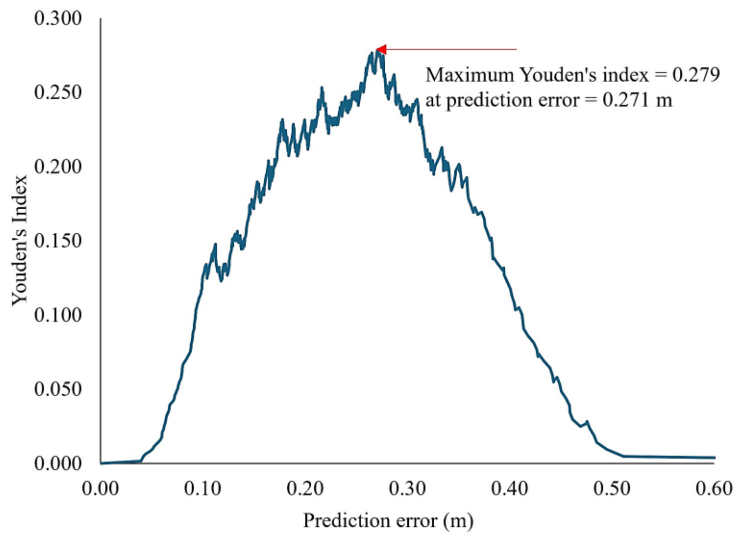

Figure 5. Youden's index as a function of prediction error.

According to the found Youden's index prediction, errors were dichotomized into low prediction errors (<0.271 m) and high prediction errors (≥0.271 m), The 2X2 contingency table of the association between optimal vs non-optimal serve distance with low versus high prediction errors provide the results shown in Figure 6.

Figure 6 shows that serving an optimal serve dramatically increases the chance of achieving high prediction error by almost 28%. The OR = 3.53, which is the effect size, is interpreted as how many times the odds of high to low prediction error is increased when performing an optimal serve against a non-optimal serve.

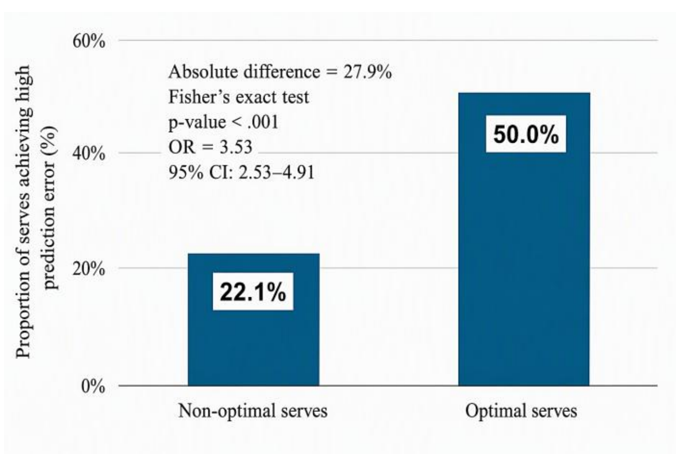

Figure 6. Proportions of high prediction error for non-optimal and optimal serves.

DISCUSSION

Although prediction error does not constitute a direct measurement of aerodynamic instability, it provides a practical proxy for deviations from the theoretical projectile trajectory. Several methodological precautions were implemented to minimize alternative sources of error. This includes rigorous camera calibration, synchronized image acquisition, standardized data processing, and strict inclusion criteria requiring minimal or no ball spin. Under these controlled conditions, systematic differences in prediction error across flight distance groups are more plausibly attributed to changes in ball flight behaviour than to measurement variability. Nevertheless, future studies employing direct measurements of in-flight aerodynamic forces or higher resolution motion capture systems could further validate prediction error as an indicator of float behaviour.

This study showed that the trajectory prediction error was used as an operational measure of trajectory deviation, consistent with previous approaches linking deviation from expected parabolic motion to float behaviour. This relation is nonlinear since there was a peak at the 16-17 m distance. That supports the idea of using the serving distance as a tool to achieve the ideal speed that will result in trajectory deviation. Although maximum values were found at that distance, there is a wider range distance (16-18 m), within which aerodynamic forces will push the ball away from the predicted landing point. In that sense a volleyball player can focus on serving at the last three meters of the opponents' court, provided that he is behind the serve line. That secures his accuracy of giving the ball the appropriate initial speed without using any equipment. This finding is consistent with the theoretical expectation (MacKenzie et al., 2012) that float behaviour emerges when the ball velocity decreases into a specific critical speed during flight.

On the same note previous wind tunnel experiments on Mikasa V200W, showed that sudden lateral and lift forces were generated only within a specific Reynolds number range. The result of that was unpredictable trajectory deviations (Hong et al., 2020). Similarly, Tamaru et al. (2021) demonstrated that float serve trajectories are strongly influenced by the initial ball velocity. The Reynolds number is directly proportional to ball velocity and velocity decreases as a function of distance. This relationship supports the present findings of a specific serve distance range within which float behaviour is most likely to occur. In support of that, Kawakami et al. (2017) concluded that changes in the ball's trajectory occur within a critical velocity range.

The present study extends previous findings by demonstrating that these aerodynamic effects can be identified through flight distance, providing a practical bridge between controlled laboratory findings and real-world performance. Float serve behaviour depends on two essential conditions. (a) Minimal or zero ball rotation and (b) Ball velocity within a critical range. The first condition, minimal rotation, is determined by the mechanics of ball contact. Spin is introduced when the point of force application does not align with the ball's centre of mass. For example, a contact above the centre produces topspin. This point can be easily addressed during training, as rotation is visually observable during flight. Players can therefore receive immediate visual and audio feedback and adjust their contact point accordingly to minimize spin.

The second condition, achieving the critical velocity range, is considerably more complex. Aerodynamic studies have shown that float behaviour occurs within a narrow velocity window corresponding to a critical Reynolds number regime (Hong et al., 2020). However, this speed is reached during flight as the ball decelerates due to aerodynamic drag. So, it is not the initial speed that the player gives at the ball during hand contact.

From a coach's point of view guiding a player regarding the optimum initial speed is very challenging. That is because speed cannot be monitored without the use of electronic devices. Although equipment such as radar devices can assist in measuring ball velocity, they are not always available and are impractical for continuous use during regular training sessions.

Given that velocity decreases continuously during flight, the results of the present study suggest that flight distance can serve as a practical proxy for the initial speed and therefore velocity decay. More specifically it was found that:

- At shorter distances (<16 m), the ball's initial speed is already low and does not enter the critical range
- At intermediate distances (~16-17 m), the ball decelerates into the critical velocity range, increasing the likelihood of aerodynamic instability
- At longer distances (>17 m), although float behaviour may still occur, float serve execution becomes less consistent due to increased variability and control demands

Those results agree with Tamaru et al. (2021) findings. They noted that trajectory irregularities can be found under specific combinations of the ball's speed and rotation. Therefore, float serve path deviations are not uniformly present across different trajectories.

Beyond its practical value, the proposed coaching approach is also consistent with established principles of motor learning. Players, instead of trying to focus on variables that are difficult to perceive during performance, such as ball velocity, they can focus on an externally observable movement outcome. That is the serve flight distance. Research has consistently shown that directing attention towards movement effects, like the trajectory or landing point of the ball, rather than toward body movements or internal mechanics, enhances both motor performance and learning (Wulf et al., 2002). Therefore, using serve distance as a coaching constraint provides a simple external performance goal that allows athletes to self-organize their movement patterns and consistently produce the desired trajectory.

rom a practical point of view, the identification of a target distance of approximately 17 ± 1 m provides a simple and easy to use tool when training float serves. Attempting to control initial speed directly is difficult to quantify in real time. Coaches and players can use distance-based targets as guide for the proper float serve execution. By instructing players to consistently target a landing zone at approximately 17 m, it becomes possible to indirectly achieve the aerodynamic conditions required for float behaviour. The distance range of 17 m is important, because it provides a margin of tolerance regarding missing the target. When a player is slightly under-hitting the 17 m target (~16 m), his serve remains within the effective range. On the other hand, when a player is slightly over-hitting the 17 m target (~18 m), he can still produce float behaviour, although with reduced consistency. This makes the 17 m target both optimal and robust. It allows players, regardless of gender or skill level, to develop float serves through trial-and-error learning method.

Although the present study focuses specifically on volleyball float serves, the same concept extends beyond this particular skill. In many sports, the desired performance depends on physical or biomechanical variables that are difficult to observe during practice. The present study demonstrates that such variables can sometimes be approached indirectly. This can be done through simple, externally observable performance targets. In the case of volleyball float serves, flight distance provides a practical proxy. A link between the aerodynamic conditions and the trajectory deviation. That offers a simple evidence-based framework that translates complex biomechanical principles into an easily applicable training strategy.

The threshold identified through ROC analysis should be interpreted as a practical decision threshold rather than evidence of a discrete aerodynamic boundary. Prediction error remains a continuous variable, and the magnitude of aerodynamic instability is similarly expected to vary continuously. The cutoff produced by ROC was introduced only to facilitate the interpretation of the Fisher's exact analysis and to provide a practically meaningful criterion for distinguishing larger from smaller trajectory deviations in an applied coaching context.

Figure 7 summarizes the proposed conceptual coaching framework, illustrating how the recommended flight distance can be applied in practice.

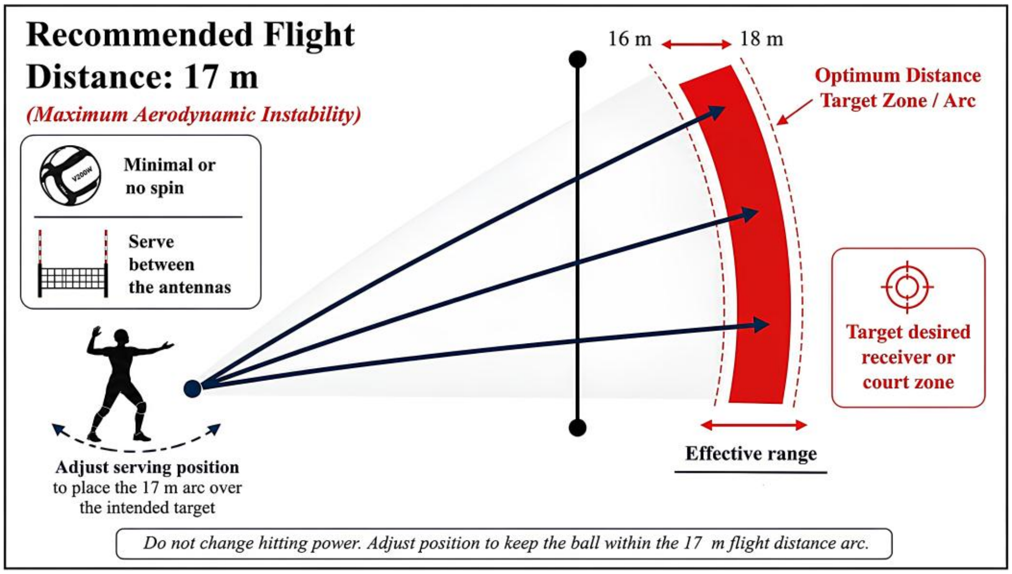

Figure 7. Conceptual coaching framework for applying the recommended float serve flight distance.

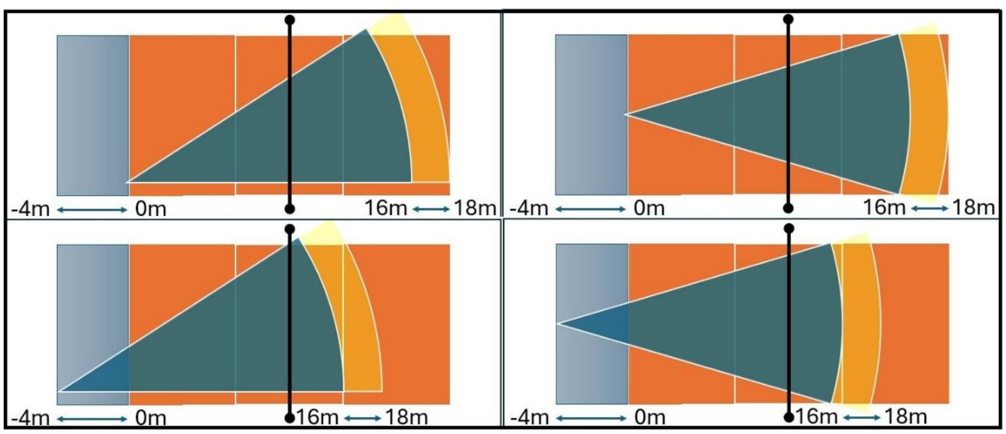

Figure 8. Application of the conceptual coaching framework from different serving positions.

The findings also introduce a spatial interpretation of the optimal serving distance. Since the server can be considered as the centre of the ball's motion, the 17 m distance defines an arc-shaped region across the opponent's court (Figure 8). The highlighted band represents the recommended flight distance range of 17 ± 1 m. This has important tactical implications since it can be used while respecting both the players and coaches' preferences. All players have a personal preference regarding the position from which they serve. The same way coaches have target preferences, either a zone or a receiving player, according to their strategy against every match opponent team. Figure 8 illustrates that (a) the optimal landing zone varies depending on the server's position, (b) different serving positions shift the arc and (c) coaches can reposition the arc to suit their strategy plans. When players serve from lateral positions (zones 1 or 5) the direction of the serve affects the distance of the target from the net. Cross court serves should land around 2.5 m closer to the net to maintain the 17 m flight range. If we consider that the receivers of a team stand around 5-6 m from the net there are two choices regarding the team's strategy. The receivers of a team when expecting a float serve, usually stand about 5-6 m away from the net. Serves from the end line will force them to use overhead passing technique. Serves taken from 3-4 m behind the end line will force them to use underarm reception technique. So, both the players and the coaches can benefit using the 17 m serve range. Players can use it during training as a practical reference for consistently producing the recommended flight distance. Coaches can use it when designing the per rotation serving strategies in games.

Float serves can still deviate from the normal parabolic trajectory at distances greater than 17 m, but this seems to come with some disadvantages. Sending the ball farther requires greater force which makes it more difficult to keep the ball not spinning. In addition, aiming at greater distances is harder so players will not be as accurate as in shorter flight range. An increased flight duration will also help the receivers, giving them more time to adjust their position. Overall, while longer serves may still deviate, they are likely to be less accurate, less consistent and therefore less effective. Although the present study used a single highly experienced player, the objective was not to investigate player performance, but the aerodynamic behaviour of the volleyball following the hit. A single server was deliberately selected to ensure consistent execution of non-spinning float serves while systematically producing a wide range of realistic flight distances. Under these conditions it was the ball trajectory and not the player's technique that was observed. Nevertheless, future research should examine whether players of different ages, sexes and competitive levels can produce the same flight distance conditions consistently during training and competitions. Such studies would help determine the practical generalization of the proposed approach across broader volleyball populations. Future research should also examine whether similar results are observed with jump float serves. The standing float serve is a basic skill that helps players learn how to control ball spin and distance. It is essential that players should practice this type of serve first, before moving on to more advanced serves like the jump float or jump spin. When executing a standing float serve, coaches may instruct players to target landing zones within this distance range as a simple, equipment-free method to approximate the conditions associated with increased trajectory instability.

CONCLUSIONS

In summary, this study shows that deviations from ideal parabolic trajectory in volleyball float serves are distance dependent. The critical flight range where the greater errors were found is 16-17 m. Results showed that a distance of approximately 17 m is associated with increased trajectory deviation and may serve as a practical reference in training. The flight range was linked with the initial ball speed, giving players and coaches an easy-to-use tool for training and for games strategies. The identification of a distance-based target (17 m) provides a practical coaching framework through which players and coaches can achieve the required goal of floatation without relying on specialized equipment.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. Contributions are specified according to the CRediT (Contributor Roles Taxonomy) as follows: Conceptualisation: AL, IK, KS, KB. Methodology: AL, IK, KS, KB. Formal analysis: MK. Investigation: AL. Data curation: AL. Writing - original draft: AL. Writing - review & editing: AL, IK, KS, MK, KB. Supervision: KB.

All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

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