BALL SPEED PREDICTORS IN SLIDE ATTACKS IN FEMALE VOLLEYBALL PLAYERS

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The purpose of this study was to investigate ball speed predictors of slide attacks and provide direct parameters for their proper execution. Healthy collegiate female volleyball players (n = 8) were recruited. After a warm-up, 3 successful slide attacks per participant and their ball speed were recorded using an 8-camera motion capture system and a radar gun. COM approach speed, maximum angular velocity of pelvis and torso rotation in the arm cocking phase, and maximum angular velocity of torso rotation, shoulder IR, and elbow extension in the arm acceleration phase were calculated for the trial with the fastest ball speed. The multiple stepwise regression was not statistically significant (p = .098). The findings indicate that peak torso rotation angular velocity in the arm cocking phase and peak shoulder IR and peak elbow extension angular velocities in the arm acceleration phase may be important contributors to the ball speed in slides.

KEYWORDS: slide attack, kinematics, spike, velocity, performance.

INTRODUCTION: Attacking is the single most important volleyball skill which directly impacts the successfulness of matches in high level volleyball (Palao, Santos, & Ureña, 2004; Reeser et al., 2010). An elite volleyball player practicing between 16 and 20 hours per week executes approximately 40,000 spikes during one season (Kugler et al., 1996). Previous literature highlighted jump height and ball speed as key determinants for the success of regular spikes (Forthomme et al., 2005; Fuchs et al., 2021). For the ball velocity of a regular spike in volleyball, Wagner et al. (2012) emphasized the relevance of pelvic and torso momentum, the transition into angular velocities in the shoulder internal rotation and flexion, as well as elbow extension. However, very little is known about the biomechanical characteristics of more complex attacks, such as slides. The purpose of this study was to investigate the predictors of ball speed in slide attacks in female volleyball players and provide coaches and players with direct spiking technique guidelines. It was hypothesized that the COM approach speed, maximum angular velocity of pelvis and torso rotation in the arm cocking phase, and maximum angular velocity of torso rotation, shoulder IR, and elbow extension in the arm acceleration phase will be associated with ball speed in slide attacks.

METHODS: The study received an approval from the Point Loma Nazarene University's Institutional Review Board (IRB). Eight healthy collegiate female volleyball players actively participating in volleyball were recruited (age = 19.63 ± 1.06 years, height = 178.59 ± 6.18 cm, weight = 68.04 ± 3.64 kg). Exclusion criteria included having any active injury or a history of surgery 6 months prior to the start of the study.
Spatiotemporal, kinetic, and kinematic data were collected using an 8-camera motion capture system (Kestrel, Motion Analysis Corp., Santa Rosa, CA) integrated with the Cortex motion capture software (C-Motion, Germantown, MD) at a sampling rate of 240 Hz. A Sport 2 radar gun was used to measure the ball speed after contact (Stalker Sport, Richardson, TX).
The data collection was performed in a gym. The net was adjusted to the women's regular net height (2.24m) and the motion capture cameras were set up around the volleyball court. After a 10-minute dynamic and 10-minute volleyball-specific warm-up, 40 passive reflective markers (1.4cm diameter) were placed directly on various upper and lower body landmarks to estimate joint locations and bone segments. Four static trials were collected for each participant to create a template for data processing. Each participant was then allowed to practice slide attacks to familiarize themselves with the motion capture set-up and marker placement. Once ready, each participant performed slide attacks until 3 successful trials per participant were recorded. The trial with the fastest ball speed was selected for further analysis, where COM approach speed, maximum angular velocity of pelvis and torso rotation in the arm cocking

phase, and maximum angular velocity of torso rotation, shoulder IR, and elbow extension in the arm acceleration phase were calculated.
All kinematic computations were performed using Visual 3D software (C-Motion Inc., Germantown, MD), while R (Version 4.0.2; R Core Team, 2020) and RStudio (Version 1.3.1093; RStudio, 2020) were used for the statistical analysis. The ball speed was the continuous dependent variable, whereas the COM approach speed and maximum angular velocities of different joints during selected phases were continuous independent variables. After obtaining summary statistics, a multiple stepwise regression ($\alpha = .05$) was done to determine an equation with the best fit that predicts the ball speed using a linear combination of the aforementioned biomechanical parameters.

RESULTS: Table 1 lists peak velocities of different segments and kinematic variables during the arm cocking (AC) and arm acceleration (AA) phases. Negative values for the peak torso, shoulder, and elbow angular velocities were omitted (Table 1), however, peak torso angular velocity had a leftward rotation or rotation towards the ball, peak shoulder angular velocity had the direction of internal rotation (IR), and peak elbow angular velocity had the direction of elbow extension.

Table 1: Maximum values of linear and angular spike kinematics (n = 8).

Variable	Mean ± SD
Ball Speed, m/s	16.0 ± 1.1
COM Approach Speed, m/s	4.2 ± 0.5
Peak Pelvis Velocity (AC), deg/s	379.5 ± 98.1
Peak Torso Velocity (AC), deg/s	65.8 ± 65.3
Peak Torso Velocity (AA), deg/s	408.1 ± 39.0
Peak Shoulder Velocity (AA), deg/s	1014.3 ± 472.8
Peak Elbow Velocity (AA), deg/s	184.5 ± 170.6

Figure 1 illustrates the time series progression of the torso, shoulder, and elbow angular velocities, respectively, throughout the arm cocking (take-off to MER) and arm acceleration (MER to impact) phases, where MER stands for the maximum external rotation of the shoulder.

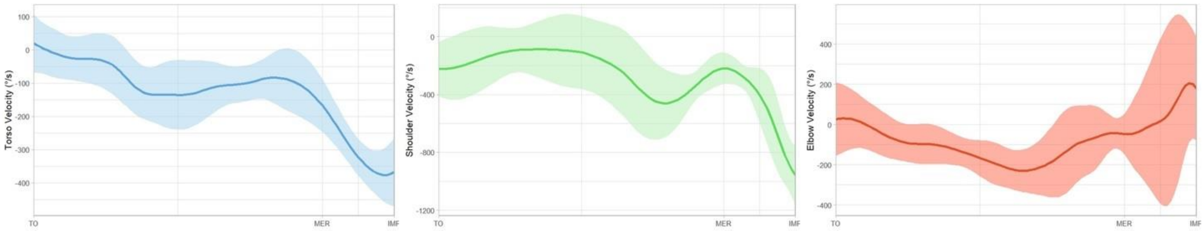

Figure 1: Time series plots (n = 8) for torso, shoulder, and elbow angular velocities (deg/s).

The multiple stepwise regression analysis indicated that peak torso angular velocity in the arm cocking phase and peak shoulder and peak elbow angular velocities in the arm acceleration phase should be included as part of the ball speed prediction model. The regression model with unadjusted $R^2 = 0.761$ and $p = .098$ was achieved and the equation was ball speed = 16.067 - 0.012*Peak Torso Velocity (AC) – 0.001*Peak Shoulder Velocity (AA) + 0.004*Peak Elbow Velocity (AA). The multiple stepwise regression was not statistically significant ($p = .098$) and the standard error of estimation of ball speed by the model was 0.727 m/s with the peak torso angular velocity during the arm cocking phase as the most influential predictor (beta = -.012, $p = .047$).

DISCUSSION: This study's findings did not fully support the hypothesis that a combination of different biomechanical variables would reliably predict the ball speed in slide attacks. Even though the predictive model explained roughly more than half of the variance in ball speed, it was not statistically significant and did not include the COM approach speed, peak transverse pelvis angular velocity in the arm cocking phase, or peak transverse torso angular velocity in the arm acceleration phase as relevant factors.

Jump height and ball velocity are two main factors that impact the success of spikes in volleyball (Forthomme et al., 2005; Fuchs et al., 2021). With jump height, research highlighted the importance of approach speeds in defining the optimal jump mechanics (Wagner et al., 2009). Systematic reviews have found strong indications that the spike jump height depends on the velocity of the COM (Oliveira et al., 2020). Despite this existing knowledge regarding the importance of the approach speeds and jump heights in spike performance and unlike hypothesized, the regression model did not include the COM approach speed.

Maximal angular velocities of the upper extremity indicated a role in ball speed of slide attacks, as found in previous studies (Fuchs et al., 2019; Wagner et al., 2012). Aguinaldo and Escamilla found the trunk rotational torque to be the primary source of power production for ball velocity in baseball pitching, due to the trunk's large segmental mass (2019). Wagner et al. highlighted the relevance of the torso momentum and shoulder IR velocity in regular spikes of male volleyball players (2012). Similarly, the trunk and shoulder motion were the key variables in predicting the ball speed in slide attacks as well, although neither the peak torso rotation angular velocity in the arm cocking phase nor the peak shoulder IR angular velocity in the arm acceleration phase were statistically significant.

When it comes to the elbow extension angular velocity, previous studies highlighted its importance in predicting the ball speed of regular spikes in male volleyball players (Wagner et al., 2012). Fuchs et al. reported similar findings in a basic female volleyball spike (2019). Peak elbow extension angular velocity in the arm cocking phase of slide attacks tended to correlate with the ball speed, which aligned with the findings from previous studies.

Proximal-to-distal transfer of segmental angular velocity characterizes efficient baseball pitching biomechanics (Scarborough et al., 2018). As one segment of the body reaches its peak velocity, it initiates rotation of a segment proximal to it and allows the flow of mechanical energy through the kinetic chain (Aguinaldo & Escamilla, 2019). In this study, the torso rotation reached its peak velocity first at 70% of the take-off to impact phase, followed by the shoulder IR at 80%, and the elbow extension at 98% (Figure 1). According to the time-series data, it can be concluded that female volleyball players display the typical proximal to distal behavior during slide attacks, as found in regular volleyball attacks and baseball pitching (Marshall & Elliott, 2000; Scarborough et al., 2018). Interestingly, some researchers have found that the maximal elbow extension angular velocity of the hitting arm sometimes occurs before the maximal shoulder IR angular velocity (Serrien, Goossens, & Baeyens, 2018; Wagner et al., 2012). It is believed that this premature elbow extension acts as a defense mechanism in order to reduce the moment arm for the shoulder IR. This way, the elbow extension angular velocity reduces and prevents overextension of the elbow, thus, reducing the risk of possible muscle or joint injury (Wagner et al., 2012). However, this behavior was not displayed in this study's sample.

This study adds valuable baseline information to the limited research on slide attacks, but it is not without limitations. The major limitation of this study is its sample size (n = 8), largely impacted by the COVID-19 pandemic. A small sample size could have affected the observed R^2 and led to a type II error. In addition, slides are typically performed by middle blockers; even though all participants of this study were actively participating in volleyball as hitters, they were not all middle blockers. The single group study design prevented the comparison of ball speed predictors in slide attacks between collegiate and other levels of volleyball. It is possible that biomechanical differences in techniques observed among players of different levels exist. Future studies should prioritize recruiting a larger sample size of middle blockers, so that the consistency of slide attack techniques and proficiency is achieved and the probability of observing statistical significance, where present, is maximized. Another limitation of this study is the exclusion of the lower body segments in the analysis model, regardless of their reported contribution to the transfer of energy up the kinetic chain and their effects on the spike jump mechanics in volleyball (Aguinaldo & Escamilla, 2019; Wagner et al., 2009). This study attempted to take an innovative approach to volleyball biomechanics research and perform the data collection in the environment where volleyball players compete. However, it also limited the ability to investigate GRFs and lower extremity kinetics, which are important factors in optimal jump and jump height mechanics (Forthomme et al., 2005; Wagner et al., 2009).

CONCLUSION: This study represents the first known study to investigate the biomechanical predictors of ball speed in slide attacks in female volleyball players. The findings indicate that peak torso rotation angular velocity in the arm cocking phase and peak shoulder IR and peak elbow extension angular velocities in the arm acceleration phase may be important contributors to the ball speed in slide attacks. Still, the most influential contributor to the ball speed is peak torso rotation angular velocity during the arm cocking phase. Therefore, when it comes to technique-related player improvements, coaches should emphasize the importance of achieving a large trunk rotation and doing so quickly throughout the arm cocking phase. However, additional research on a larger sample size is needed to define how improvements in technique impact injury risk, address the effects of fatigue, and investigate the contributions of the lower extremity kinetics and kinematics and shoulder and elbow forces and torques to ball speeds in slide attacks.

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