GROUND REACTION FORCES OF COMMONLY USED VOLLEYBALL BLOCKING APPROACHES

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Abstract:

Aim: The purpose of this study was to quantify ground reaction forces for some of the most commonly utilised volleyball blocking approaches and to examine their kinetic and kinematic characteristics.

Basic procedures: The study was comprised of 18 healthy recreationally active women who volunteered to participate. Immediately after completion of the warm-up protocol, subjects performed 5 blocking approaches: stationary blocking approach (SBA), shuffle block to the right (SHBR), shuffle block to the left (SHBL), swing block to the right (SWBR) and swing block to the left (SWBL). In order to allow adequate recovery, each trial was randomly assigned and separated by a 1-2 minute rest interval. A uni-axial force plate with data acquisition system sampling at 1000 Hz was used to measure ground reaction forces.

Main findings: SWBR and SWBL unveiled the greatest peak concentric force and rate of force development when compared to SBA, while no difference was observed when compared to SHBR and SHBL.

Results: No significant differences were observed in peak landing force, impulse, and vertical jump height between any of the blocking approaches examined in this study.

Conclusions: Knowing biomechanical characteristics of some of the most commonly utilised volleyball blocking approaches may help athletes to appropriately respond and quickly adjust to the opponent’s attacking position. Kinetic and kinematic variables are likely to be augmented with an advanced level of competition and can be trained and improved by properly designed and implemented strength and conditioning programmes.

Introduction

Volleyball is a highly popular international sport. It is a fast-paced game in which players are required to make quick decisions within short periods of time on what volleyball technique they should use in order to put their team in the best position to score a point and potentially win the game. Volleyball is a complex sport where each player is required to know how to pass, set, and serve the ball, while the majority of players based on their playing position need to be proficient with performing blocking and attacking approaches [1,2,3].

Lidor and Ziv reviewed a large number of scientific studies focusing on physical, physiological, and on-court performance variables [4]. They found that players at higher levels of competition are taller, heavier, and obtain superior vertical jump values [4]. While volleyball is mainly an anaerobic sport, certain levels of aerobic capacity are required to allow optimal repetitive performances. In previous research, it has been indicated...
that aerobic capacities of volleyball players, on average, are similar to those of basketball players (44.0 - 54.0 mL·O₂·kg⁻¹·min⁻¹) [4,5,6,7], which can be highly beneficial for optimal recovery between multiple highly explosive blocking and attacking movements.

Besides service points and reception errors, successful blocking has been highly correlated with winning probability [1,2,3]. This motion is one of the most complex movements in the game, and in order for each player to achieve high proficiency, it requires a significant amount of practice time. The team that accumulates more blocks and points resulting from successful blocking formations is more likely to score a point and increase the overall chances of winning a game [1]. It has been found in previous research that the team’s winning chances are decreased 0.7 times for every ball blocking error during a game span [3]. Furthermore, Eom and Schutz’s findings based on 72 in-season game film analyses are in agreement by those obtained by Silva et al., stating that blocking is one of the most important game elements for determining success in the game of volleyball [1,2]. Hence, it can be assumed that coaches should spend a considerable amount of practice time developing this skill and perfecting its efficacy.

Despite the significant amount of literature addressing the importance of blocking techniques in volleyball [1,2,3,8], in order to increase the chances of winning a game, a margin of points earned through successfully executed blocking approaches is not as large as someone may think. In men’s volleyball, 11-15 points per set typically come from the attack, 2-3 points from successful blocking formations, 1-2 points from service, and 6-9 points from opposing team errors [9]. Interestingly, in women’s volleyball, greater emphasis is placed on attacking and blocking movements, suggesting that 12-16 points typically come from the attack, 2-4 points from successful blocking formations, 1-2 points from service, and 5-8 points from opposing team errors [9]. While the overall number of points required to win a set in a volleyball game is mainly attributed to different scoring opportunities, a successfully executed blocking motion is the first line of defense which can immediately transition into an attacking opportunity and scoring a direct point [10]. Thus, if we combine the significance of this motion with the number of times that the effective blocking approaches occur during a set in a volleyball game, we can recognize that player’s ability and proficiency to successfully complete this task may play a crucial role in the final game outcome.

A majority of current scientific volleyball literature is focused on kinematic parameters of various hitting or blocking techniques, but to date, in no research have kinetic parameters been quantified. In one of the initial studies, Buekers found that despite the longer preparation time, the running step technique demonstrated significantly faster movement times when compared to the slide and cross-over blocking approaches [11]. Dona et al. conducted a pilot study on an elite cohort of athletes addressing biomechanical footwork parameters of the three most commonly used blocking techniques in volleyball [12]. A marker-based motion capture system was used to quantify upper and lower body kinematic variables during the slide, running, and jab cross-over steps. Interestingly, no differences were found in vertical jump height and time of lateral movement and jump [12]. In another study high-speed videography was used to assess kinematic variables such as time needed for take off, time to place hands above the net, jump height and hands penetration with the purpose of identifying specific techniques that would elicit an optimal blocking approach [13]. While unable to observe the difference in time to take off the ground, researchers found that arm swing during a blocking motion may have a significant effect on the efficacy of this movement [13]. The blocking approach with full arm swing revealed 3.4% and 1.4% improvement in vertical jump height and 17.4% and 9.2% improvement in hand penetration capability when compared to traditional and “chicken wing” arm action, respectively [13]. These findings were coupled in a similar study conducted by Ficklin et al., in which the authors yielded analogous results [14]. The traditional blocking approach with no arm swing demonstrated significantly greater approach time and lower maximal vertical jump height when compared to a blocking motion with an arm swing [14]. Despite the fact that players spent a longer time in the air, increased take-off velocity and increased maximal jump height made the blocking motion with arm swing superior when compared to traditional blocking motion with no arm swing [14]. However, this may be challenging for the quick and appropriate adjustments necessary to respond to the opponent’s attacking schemes [14]. Interestingly, while in a few previously mentioned studies some of the critical kinematic parameters related to successful volleyball performance were observed, kinetic variables were not quantified.

Despite volleyball being one of the most popular sports worldwide, there is a lack of scientific literature in which some of the essential kinetic characteristics of this sport would be addressed. Without knowing the fundamental components of various blocking motions, it may be challenging to understand how certain performance improvements can be made. Knowing what kinetic and kinematic variables to monitor and how to manipulate the resistance training programme in order to optimise blocking motion capability can be crucial for prime athlete development, especially with increased utilisation of technology and sports performance monitoring equipment.
It is a well-known concept that properly designed and implemented resistance training programmes play an essential role in athletes’ performance enhancement. The findings of Sheppard et al. indicate that the ability to produce force, tolerate high loads, and optimize stretch-shortening cycle capabilities play an important role regarding the augmentation of jump performance in volleyball [15]. Furthermore, Fry et al. found that the implementation of properly designed strength and conditioning programmes is necessary for improvements in performance and physical characteristic variables, regardless of the athlete’s playing status [16]. Thus, knowing and understanding the kinetic and kinematic properties of various blocking approaches in the game of volleyball can be highly beneficial for individual and team player development.

Therefore, the purpose of this study was to quantify ground reaction forces for some of the most commonly utilised volleyball blocking approaches (two-legged stationary, shuffle block to the right, shuffle block to the left, swing block to the right, and swing block to the left) and examine their kinetic and kinematic characteristics.

Material and methods

subjects

The study was comprised of 18 healthy recreationally active women (\(\bar{x} \pm SD\); body height = 167.7 \(\pm\) 7.9 cm, body mass = 63.3 \(\pm\) 6.3 kg, age = 20.3 \(\pm\) 0.9 years, playing experience = 6.4 \(\pm\) 2.8 years) who volunteered to participate. Each subject completed the informed consent form prior to any testing procedures. Subjects with any musculoskeletal injuries were excluded from the study. All procedures performed in this study were previously approved by the University’s Institutional Review Board.

Procedures

Upon arrival at the testing facility, subjects completed a standardised warm-up protocol composed of a treadmill run at an individually determined moderate intensity level for 5 minutes. This was followed by a series of dynamic warm-up exercises such as high knees, butt-kicks, lunges with twist, knees to chest, high skips, lateral slides, and lunges. Immediately after completion of the warm-up protocol, subjects performed 3 repetitions of each blocking approach commonly observed in the game of volleyball. In order to allow adequate recovery, each trial was separated by a 1-2 minutes rest interval. Additionally, the order of testing the different blocking techniques was randomly assigned. The traditional two-legged stationary blocking approach involved no steps (see Figure 1a). Unlike the other blocking motions, the stationary blocking approach did not involve any lateral motion, and solely examined maximal vertical displacement from a stationary position. The shuffle block to the right required leading with a lateral step with the right foot before initiation of the block jump (see Figure 1b). The shuffle block to the left required leading with the left foot before initiation of the block jump (see Figure 1c). The swing block to the right started by taking a first big explosive step with the right foot followed by a cross-step with the left foot before the block jump (see Figure 1d). The swing block to the left is performed identically to the swing block to the right, but in the opposite direction (see Figure 1e). During each jump, subjects were instructed to focus on achieving maximal vertical jump height.

![Figure 1](image-url). Example of blocking approaches used in this study: a) traditional/stationary blocking approach, b) shuffle block to the right, c) shuffle block to the left, d) swing block to the right, and e) swing block to the left. The numbers above the arrows indicate the order of the steps.
Equipment

A 0.91 m x 2.4 m uni-axial force plate (Rice Lake Weighing Systems, Rice Lake, WI) and data acquisition system (Biopac MP 150, Goleta, CA) sampling at 1000 Hz were used to measure ground reaction forces. A volleyball net was positioned at the standardised height of 2.24 m to correspond to the popularly-implemented women’s volleyball regulations. A pole with a volleyball was set above the net height as a target to simulate game-like conditions and to elicit a maximal vertical jump effort. The experimental set-up is shown in Figure 2.

Variables

Peak concentric force [N] was determined from the highest point on the force curve during the concentric phase of the block jump movement, while peak landing force [N] was determined from the highest force recorded during the landing phase of the motion. Impulse [N·s] for all blocking approaches was determined as the area under the ground reaction force curve greater than the subject’s body mass. Rate of force development [N·s⁻¹] for the blocking approaches that did not originate on the force plate was determined as a slope from the subjects’ initial contact with the force plate until the highest ground reaction force value during the concentric portion of the jump. For the stationary blocking approach, the rate of force development [N·s⁻¹] was calculated from the lowest point of the countermovement vertical jump phase to the highest ground reaction force value observed during the concentric phase of the movement. Vertical jump height [cm] for all approaches examined in this study were derived from flight time.

Statistical analysis

Descriptive statistics (x ± SD) were calculated for each variable observed in this study. One-way analysis of variance (ANOVA) with post hoc group comparisons using Bonferroni adjustment were used to analyse the data and observe differences in kinetic and kinematic variables between the 5 most commonly used blocking approaches examined in this study. Levene’s test was used to test for homogeneity of variance. The signifi-

Results

Mean values and standard deviations (x ± SD) for each blocking approach are presented in Table 1. Levene’s test for homogeneity was not significant (p > 0.05), indicating the equality of sample variances for each of the dependent variables. One-way analysis of variance (ANOVA) revealed that the swing block to the right and swing block to the left had significantly higher peak concentric force compared to stationary blocking approach (p = 0.041 and p = 0.002, respectively), while no differences were found when compared to both shuffle blocking approaches (p > 0.05). In addition, the swing block to the right and the swing block to the left exhibited a significantly higher rate of force development when com-
for participation in this study were recreationally active females with previous volleyball playing experience. Hence, we may conclude that our data properly fits within previous research findings intended to link maximal vertical jump ability with the appropriate level of playing competition.


discussion

Despite the lack of research addressing kinetic and kinematic characteristics of some of the most commonly used basketball dunking approaches in volleyball, several of similarities and differences have been found compared to previous scientific literature. One of the main and the most commonly observed physical characteristics crucial for successful blocking and spiking performance is maximal vertical jump height. Lidor and Ziv found that maximal vertical jump height values are noticeably different between players participating at various levels of volleyball competition for female volleyball players [4]. Average vertical jump heights between the United States women’s national team members and National Collegiate Athletic Association (NCAA) Division-III student-athletes were ranged between 52.4±4.5 cm and 30.2±7.2 cm, respectively [4]. If we exclude potential errors that may exist between various methodologies used to determine maximal vertical jump height, we may still determine that one of the main differences can be found in the jumping ability of the athletes [4]. Vertical jump values for all blocking approaches examined in this study fell below the previously mentioned values. The average value for all five blocking approaches in this study was 25.7±5.6 cm. Considering that the cohort of subjects recruited for participation in this study were recreationally active individuals, this discrepancy is not surprising. Athletes competing at the NCAA Division-III level of competition and above are provided with organized practice and resistance training schedules. Also, a certain level of athletic performance capability for these athletes is required in order to be a member of their team. On the other hand, subjects recruited in this study included recreationally active females with previous volleyball playing experience. Hence, we may conclude that our data properly fits within previous research findings intended to link maximal vertical jump ability with the appropriate level of playing competition.

Considering that there is a lack of scientific literature addressing kinetic characteristics of various volleyball motions, one of the first studies conducted by Coutts in 1982, attempted to quantify the kinetics of 2 simplistic volleyball jumping techniques without a run-up component [17]. The blocking approaches used in Coutts’s methodology are most similar to the shuffle blocking approaches examined in this study [17]. Although no differences in maximal vertical jump height were found, Coutts’s findings indicate that the average peak concentric force for the step-close approach was 1203±333 N [17], which is noticeably lower than the average shuffle block to the right and shuffle block to the left forces observed in this study, 1885.9±323.8 N and 1863.7±364.1 N, respectively. However, this comparison should be interpreted with caution as the cohort of subjects used in Coutts’s study included a combination of male and female subjects without indicating demographic and anthropometric subjects information which could significantly affect the outcome of the final results. On the other hand, in a recently conducted study, Cabarkapa and Fry examined kinetics for some of the most commonly used basketball dunking approaches and found that the majority of approaches with a run-up jumping component had a greater ground reaction force

<table>
<thead>
<tr>
<th>Table 1. Kinetic variables (x±SD).</th>
<th>Peak concentric force (N)</th>
<th>Peak landing force (N)</th>
<th>Rate of force development (N·s⁻¹)</th>
<th>Impulse (N·s)</th>
<th>Vertical jump height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stationary block jump</td>
<td>1600.7 ± 269.5</td>
<td>2465.8 ± 508.3</td>
<td>4772.6 ± 1756.4</td>
<td>225.2 ± 30.8</td>
<td>25.2 ± 4.7</td>
</tr>
<tr>
<td>Shuffle block to the right</td>
<td>1885.9 ± 323.8</td>
<td>2442.0 ± 496.7</td>
<td>6067.7 ± 1780.2</td>
<td>219.8 ± 33.5</td>
<td>25.1 ± 5.5</td>
</tr>
<tr>
<td>Shuffle block to the left</td>
<td>1863.7 ± 364.1</td>
<td>2400.4 ± 599.5</td>
<td>5700.7 ± 1548.5</td>
<td>224.8 ± 35.8</td>
<td>25.4 ± 5.6</td>
</tr>
<tr>
<td>Swing block to the right</td>
<td>1918.8 ± 346.2*</td>
<td>2513.8 ± 547.4</td>
<td>6867.1 ± 2143.2*</td>
<td>225.1 ± 37.2</td>
<td>26.2 ± 6.0</td>
</tr>
<tr>
<td>Swing block to the left</td>
<td>2020.4 ± 303.4*</td>
<td>2522.7 ± 578.4</td>
<td>7475.5 ± 2537.9*</td>
<td>229.8 ± 40.8</td>
<td>26.7 ± 6.3</td>
</tr>
</tbody>
</table>

* significantly different when compared to stationary block jump (p-value < 0.05)
and rate of force development magnitudes when compared to the stationary dunk approach [18]. A similar pattern can be seen in relation to the volleyball blocking methods examined in this study. Both swing blocking approaches revealed significantly higher peak concentric forces and rates of force development values when compared to the stationary blocking approach, indicating that addition of the run-up component may improve the efficacy of these sport-specific motions.

One of the most important factors that must be considered when choosing which blocking approach to use for certain in-game situations is the time required to complete the body motion. Ball placement, attacker positioning, and distance that the player has to cover are some of the greatly important factors that may influence this selection criterion. It is suggested that short response times and high force production are very important factors in order to quickly set the body in the right blocking position and achieve maximal vertical displacement [19]. Despite individual differences and variations in motion types, it is estimated that the optimal time necessary to achieve peak concentric force production is greater than 0.4 seconds [20]. Occasionally, sport-specific requirements may require rapid movements within a limited timeframe. This can potentially cause a difference between an athlete’s maximal peak concentric force capabilities and the actual maximal peak concentric force reached in a given time-limited condition, often called the explosive strength deficit [20]. Thus, it is not surprising that the swing blocking approaches demonstrated as a superior method for jumping and blocking efficiency when compared to the other blocking approaches used in the game of volleyball [19]. In order to perform a proper swing blocking approach, an athlete must likely overcome critical explosive strength deficit limitations (also known as the time deficit zone), which will allow them to achieve a greater peak concentric force compared to other time-limited blocking approaches. Although our findings indicate no difference in maximal vertical jump height, the swing blocking approaches examined in this study displayed significantly greater peak concentric forces and rates of force development magnitudes when compared to all other blocking approaches. This is in agreement with the findings of Cox et al., and further allows to support the concept of explosive strength deficit [19,20].

Another important factor that can have significantly impact on blocking performance is the utilisation of an arm swing. In previous research, it was reported that blocking technique involving a full arm swing resulted in shorter approach times and greater jump heights [13,14]. Occasionally, a middle-blocker might not have enough time to perform a blocking approach with a complete arm swing motion, which may potentially have a negative impact on achieving an optimal blocking position. Apart from the previously mentioned explosive strength deficit due to time constraints, the inability to perform a complete countermovement vertical jump motion with a full arm swing may further impair ground reaction force production as well as vertical jump height. Mosier et al. found that 13.6% of improvements in maximal vertical jump height were observed when arm swing was involved in the jumping motion, and that up to 31.5% of ground reaction forces during a vertical jump were attributed to the upper-limb involvement [21].

To couple with these findings, Vaverka et al. conducted a study focused on observing the upper body contribution to the optimal vertical jump height within a cohort of elite volleyball players and found that 38% of ground reaction force production was attributed to involvement of the upper limbs [22]. Thus, we may conclude that our findings are in agreement with those obtained in the previously mentioned literature. Higher peak concentric forces and rates of force development were observed for both swing blocking approaches examined in this study, which may be explained by laboratory experimental conditions. Our investigational setting did not involve an actual game, and blocking performance was not time-sensitive in response to an opponent. However, it was designed to mimic in-game blocking situations as closely as possible, although we did not forbid subjects to use the full arm swing blocking motion.

When considering the influence of peak concentric force, rate of force development, and vertical jump height, coaches as well as strength and conditioning practitioners need to be aware of training regimens that can lead to their improvements. Vertical jump, as one of the vital attributes for optimal volleyball performance, can be significantly improved by the application of resistance exercises and plyometric training [23,24]. Smith et al. found that resistance training implemented 3 times per week resulted in significant improvement regarding blocking performance [25]. Furthermore, plyometric training, apart from having a positive effect on jumping and throwing capacity, was found to be more effective than skill-based conditioning for overall improvements in playing abilities [26]. Thus, an amalgamation of plyometrics, strength, and power training regimens in the overall strength and conditioning training programme may allow to develop essential elements for optimal sport performance characteristics, regardless of the athlete’s level of competition [15,16,23,27].

To our knowledge, there is a paucity of research on the biomechanics of various volleyball blocking approaches, although blocking is a highly valuable skill related to the final game outcome. Further research is needed to determine differences in the kinetic and kinematic variables of various blocking approaches when the
time to complete the full upper body countermovement vertical jump is time-sensitive (e.g. in-game blocking approaches). These techniques may include but are not limited to the "chicken wing" arm swing, full arm swing, or no arm swing blocking approaches. In addition, further research should quantify and compare kinetic and kinematic variables of the same blocking approaches used in this study within a cohort of volleyball players participating at various levels of competition, such as collegiate and professional levels of competition.

Conclusions

The findings of this study indicate that swing blocking approaches exhibited greater peak concentric force and rate of force development magnitudes when compared to shuffle and traditional blocking approaches while no significant differences were observed for peak landing force, impulse, and vertical jump height between any of the blocking approaches examined in this study. Thus, knowing the biomechanical characteristics of the most commonly utilised volleyball blocking approaches may help athletes to appropriately respond and quickly adjust to the opponent’s attacking position. Kinetic and kinematic variables are likely to be enhanced with advanced levels of competition and can be trained as well as improved by properly designed and implemented strength and conditioning programmes. These data may serve as a foundation for future research projects on this topic. Additionally, these data can help coaches develop appropriate practice sessions, and strength and conditioning practitioners to prescribe effective off-court training programs. All together, these aspects may help improve individual and team performance.

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