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Technical Analysis of Volleyball Athletes' Blocking at Different Knee Take-off Angles

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Abstract: *An experimental study on the kinematics of volleyball athletes' lower limbs during blocking has shown significant differences in the buffer and immobilization phase (p=0.008‹0.01) and the impact of pedal-stretch duration, both showing significant differences (p‹0.01). Besides, consistent differences were also observed in the time spent in the aerial, the velocity at takeoff, and the height achieved, indicating that the initial speed (takeoff velocity) determines the height of the take-off and the duration of the aerial. Throughout the movement, the hip plays a crucial pivotal role, highlighting the importance of strengthening hip exercises for maintaining the stability of hip joint. Moreover, reinforcing the exercises of force and flexibility of the knee and ankle joints is essential. Analyzing volleyball athletes' blocking techniques can not only enhance training efficacy and refine technical movements but also provide a reference for injury prevention.*

Keywords: *Volleyball; Blocking; Kinematics; Knee Joint*

1. Introduction

In the study of volleyball, the application of interdisciplinary knowledge such as big data, modeling, training science, management, physiology, biochemistry, psychology, and biomechanics is extensive. Most research findings focus on the study of the EMG of upper limbs, waist, and abdominal muscles, as well as the assessment of physiological and biochemical indexes and the improvement of training methods. However, there is indeed limited research on the kinematics of lower limbs during blocking. As volleyball techniques and tactics continue to mature, and due to the rapid attack and defense transitions during intense matches, and the impact of the system of scoring a point per goal, it is crucial to strengthen the research on the kinematics of lower limbs during blocking to enable athletes to better utilize the force of their lower limbs and to improve the effect of spiking or blocking.

2. Experimental Process

Since this study is targeted at the lower limb movements of in-situ take-off, there are four primary points in the selection of pasting points, and all of them are on the right side of the body.

2.1 Experimental Apparatuses

The American-made 3D MOTION infrared point motion capture test system is employed for kinematic testing. This system is chiefly made up of infrared reflection mark points, eight (infrared) lenses, a computer and related software, and the shooting frequency is 200Hz.

2.2 Test Indexes

In this experiment, the selected indicators were chosen to meet the research needs: acceleration time, immobilization time, pedal-stretch time, aerial time, total time, rising height, maximum velocity, maximum acceleration, maximum angular velocity, and maximum angular acceleration.

2.3 Test Methods

Take off in situ for blocking. Facing the 2.43-meter-high net, lift your hands close to the net on the chest. When taking off, the arms will swing back and forth in unison. Only after grasping the movement can the test be performed. Select three angle ranges in normal squat (half squat): 60°-90°,

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90°-120°, 120°-150°, and the angle range of blocking take-off that one is used to. Take off 3 times in each angle range and take off as hard as possible. There is a 10-second interval between every two take-offs, and each take-off takes place after hearing the slogan of the tester. When testing, measure your own habitual angle first, and the other three angle ranges are tested in turn from small to large, with a 5-minute rest between every two angle ranges.

2.4 Mathematical Statistics

Copy the data to the software EXCEL2007 for analysis and processing, conduct further analysis and processing with SPSS13.0 statistical software, make a statistical description of the mean value and standard deviation of each index, and make a one-way ANOVA for the phenomena caused by different angles.

3. Working Process and Selection of Test Indexes

3.1 Division of Time Phases during Blocking

To meet the needs of the research purpose, this study only analyzes the three links of take-off, aerial and landing. Since this paper studies the movement of the lower limbs for blocking by taking off in situ, and the unified movement of upper limbs is not involved in the analysis, the take-off link starts with the movement of joint points and ends with the moment when both feet leave the ground, and this process is the take-off link. To analyze the kinematics in a more convenient, reasonable, objective and effective way, this paper divides the take-off link into two phases: buffer and pedal-stretch for research and analysis, based on the anatomical conditions such as the working form of muscles for the take-off movement of volleyball blocking.

•Buffer phase: In this study, the experiment begins when the athletes are in the upright position, starting from the knee joint point and ending at the lowest point when the speed is zero and the angle is the smallest. This process is referred to as the buffer phase of take-off.

•Pedal-stretch phase: It starts at the moment when the knee and hip joint reach the lowest point during the descent, and ends at the moment when the feet leave the ground. This process is referred to as pedal-stretch phase of take-off.

•Aerial phase: It starts with the end time of the take-off phase (that is, the moment when the feet leave the ground) and ends with the moment when the feet fall to the ground (the feet touch the ground). This process is referred to as the aerial phase.

•Landing phase: It the process from the moment when the foot touches the ground to the moment when the knee and hip are down to the lowest point again (one or both feet are possible).

3.2 Selection of Kinematics Test Indexes

The take-off and blocking process is one of the important components of the blocking technique, directly affecting the take-off velocity and blocking effect. The in-situ take-off, also known as the vertical take-off or in-situ vertical take-off, requires kinetic analysis. The in-situ take-off movement is divided into three phases: the squat acceleration phase (from the starting point to the maximum squat velocity), the squat immobilization phase (squatting from the start of immobilization to the lowest point), and the take-off pedal-stretch phase (the phase of accelerating from the lowest point to the moment the feet leave the ground). In this study, commonly used kinetic analysis indexes were selected, such as velocity, acceleration, angle, angular velocity, angular acceleration, rising height, and exercise time.

4. Kinematics Analysis of Downward Buffer Phase

During the buffer of squatting down, the velocity and angle do not decrease uniformly but rather the velocity first increases rapidly from zero velocity and then decreases rapidly back to zero velocity, while the angle first decreases rapidly and then continues to decrease slowly, presenting peak changes that conform to the characteristics of physical motion. Thus, for easier analysis, the buffer phase is specifically divided into the pre-buffer and post-buffer phases (even the immobilization phase).

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4.1 Changes of Various Kinematic Indexes in the Front Section of Buffer

In the entire squat process and during the pre-buffer phase, the athlete starts from a state of rest and the velocity increases rapidly from zero velocity, and the angle also decreases rapidly first. Only in this phase will the issues of maximum acceleration and linear velocity appear in the entire squat buffer phase.

Table 1: Comparative Analysis of Time Characteristics of the Front Section of Buffer ($\bar{x}\pm s$) n=6

	Shallow Squat	Half Squat	Deep Squat
(Acceleration) Time	0.45±0.26	0.52±0.13	0.46±0.08

Table 2: Statistical analysis of Time Characteristics of the Front Section of Buffer

Acceleration Time	Sum of Squares	df	Mean Square	F	p
Between Groups	.018	2	.009	.291	.752
Within Groups	.455	15	.030		
Total	.472	17			

As can be observed from Table 1 and 2 above, F (2, 17)=0.291, p=0.725>0.5, that is, there are no differences in the acceleration time before buffer, let alone significant differences. This suggests that there are no differences in squat time in the pre-buffer phase, whether it is shallow squat, half squat or deep squat. Meanwhile, it can also be shown that the buffer phase of squat is the preparation phase of take-off and blocking, which is a pre-judgment and selective preparation period in advance and does not play a decisive role in the take-off height.

Table 3: Comparative Analysis of Velocity, Angular Acceleration and Angular Velocity Characteristics in the Pre-Buffer Phase ($\bar{x}\pm s$) n=6

	Shallow Squat	Half Squat	Deep Squat
Maximum Angular Velocity of Hip (°/s)	158.88±75.50	204.30±66.07	260.09±51.70
Maximum Angular Acceleration of Hip (°/s²)	2470.30 ±3147.38	1064.63±465.13	1341.92±826.46
Maximum Acceleration of Hip (m/s²)	5.46±2.83	5.01±2.42	5.83±1.23
Maximum Velocity of Hip (m/s)	0.78±0.30	1.00±0.27	1.36±0.22
Maximum Angular Velocity of Knee (°/s)	204.32±54.97	206.32±41.99	238.59±19.05
Maximum Angular Acceleration of Knee (°/s²)	1896.55±1058.18	1268.10±430.36	1136.45±468.08
Maximum Acceleration of Knee (m/s²)	5.32±2.19	4.02±1.39	4.14±1.00
Maximum Velocity of Knee (m/s)	0.66±0.24	0.61±0.11	0.65±.068

Table 4: Statistical analysis of Velocity, Angular Acceleration and Angular Velocity Characteristics in the Pre-Buffer Phase

		Sum of Squares	df	Mean Square	F	p.
Maximum Angular Velocity of Hip	Between Groups	30837.528	2	15418.764	3.632	.052
	Within Groups	63687.067	15	4245.804		
	Total	94524.595	17			
Maximum Angular Acceleration of Hip	Between Groups	6652067.543	2	3326033.772	.923	.419
	Within Groups	54026975.882	15	3601798.392		
	Total	60679043.425	17			
Maximum Acceleration of Hip	Between Groups	2.030	2	1.015	.199	.822
	Within Groups	76.664	15	5.111		
	Total	78.694	17			
Maximum Velocity of Hip	Between Groups	1.023	2	.512	7.316	.006
	Within Groups	1.049	15	.070		
	Total	2.073	17			

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Maximum Angular Velocity of Hip	Between Groups	4439.338	2	2219.669	1.294	.303
	Within Groups	25737.737	15	1715.849		
	Total	30177.075	17			
Maximum Angular Acceleration of Knee	Between Groups	1980066.270	2	990033.135	1.949	.177
	Within Groups	7620309.550	15	508020.637		
	Total	9600375.820	17			
Maximum Acceleration of Knee	Between Groups	6.174	2	3.087	1.197	.329
	Within Groups	38.678	15	2.579		
	Total	44.852	17			
Maximum Velocity of Knee	Between Groups	.009	2	.005	.189	.829
	Within Groups	.372	15	.025		
	Total	.382	17			

Through analysis, it can be observed from Table 3 and 4 above chart that there are highly significant differences when F (2,17)=7.316, p=0.006‹0.01. That is, there are significant differences in the maximum velocity of hip among shallow squat, half squat and deep squat during the accelerated squat phase in the pre-buffer phase. However, through back testing (LSD), it is concluded that there are significant differences in the maximum velocity of hip between deep squat and shallow squat. This is chiefly because the hip joint increases the squat range and prolongs the squat time under the continuous action of ankle joint and knee joint, which will inevitably result in the increase of squat velocity. Meanwhile, it indicates that to maintain the body balance, particularly to keep the upper torso upright, the athlete must take the initiative to lower the upper torso and accelerate the centripetal movement of the upper torso and legs, which will inevitably result in significant differences in the maximum velocity of hip.

In the research of angular velocity and linear velocity, Meng Zhanling and Zhang Qingjun [1] oncluded that the maximum velocity angle of knee joint is the primary factor affecting the height of squat for take-off of athletes in sports schools. This demonstrates that the exertion of force and the mobilization of muscles require a suitable maximum velocity angle of knee joint. Moreover, it also shows that the knee joint plays an important role in the athletes' take-off movement, which plays a vital role in velocity and force exertion. In particular, it is the cause of frequent knee injuries in volleyball athletes and velocity skiers.

Through analysis, it can be observed from Table 5 and 6 above chart that there are highly significant differences when F (2,17)=5.800, p=0.014‹0.05; F(2,17)=22.510, p‹0.01. Through back testing (LSD), it is concluded that there are significant differences between deep squat for take-off and shallow squat for take-off in the angle corresponding to the maximum acceleration of hip, that is, F(2,17)=5.800, p=0.014‹0.05. Back testing (LSD) concluded that there are also significant differences between deep squat for take-off and shallow squat for take-off in the angle corresponding to the maximum velocity of hip, that is, there are highly significant differences when F(2,17)=22.510p‹0.01. Thus, among the velocity factors affecting the first half of the squat, the acceleration of hip and the angle of velocity exert an enormous impact.

Table 5: Comparative Analysis of the Angle of Knee and Hip Joints Corresponding to the Maximum Joint Velocity n=6

	Shallow Squat	Half Squat	Deep Squat
Maximum Acceleration of Hip	156.84±5.53	153.16±6.39	144.76±6.90
Maximum Velocity of Hip	145.40±11.25	123.76±11.20	105.42±8.27
Maximum Acceleration of Knee	161.17±11.12	164.48±7.63	158.70±11.89
Maximum Velocity of Knee	143.19±15.79	136.70±10.74	134.10±11.53

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Table 6: Statistical analysis of the Angle of Knee and Hip Joints Corresponding to the Maximum Joint Velocit

		Sum of Squares	df	Mean Square	F	p
Corresponding Angle of Maximum Acceleration of Hip	Between Groups	460.102	2	230.051	5.800	0.014
	Within Groups	594.942	15	39.663		
	Total	1055.044	17			
Corresponding Angle of Maximum Velocity of Hip	Between Groups	4806.625	2	2403.312	22.51	0
	Within Groups	1601.492	15	106.766		
	Total	6408.117	17			
Corresponding Angle of Maximum Acceleration of Knee	Between Groups	100.938	2	50.469	0.469	0.635
	Within Groups	1615.404	15	107.694		
	Total	1716.342	17			
Corresponding Angle of Maximum Velocity of Knee	Between Groups	262.692	2	131.346	0.792	0.471
	Within Groups	2488.355	15	165.89		
	Total	2751.047	17			

4.2 Changes of Various Kinematic Indexes in the Post-Buffer Phase

Table 7: Comparative Analysis of Joint Angle at the End of Buffer ($\bar{x}\pm s$*) n=6*

	Shallow Squat	Half Squat	Deep Squat
1	139.59°	101.74°	69.91°
2	149.83°	105.76°	85.42°
3	141.77°	114.25°	80.29°
4	139.13°	92.68°	72.92°
5	138.16°	99.00°	73.84°
6	140.27°	101.24°	67.12°
Average Value	141.4575°	102.4469°	74.9170°
Standard Deviation	4.27561°	7.20301°	6.78373°

As can be observed from Table 7 above, in shallow squat, the knee angle of the lowest point of the athlete's descent is 138.16°-149.83° (141.4575°±4.27561°), and the angle difference among the athletes is 11.67°; in half squat, the knee angle of the lowest point of the athlete's descent is 92.68°-114.25° (102.4469°±7.20301°), and the angle difference among the athletes is 21.57°; in deep squat, the knee angle of the lowest point of the athlete's descent is 67.12°-85.42° (74.9170°±6.78373°), and the angle difference among the athletes is 18.3°.

In his correlation research, Zeng Yuan[2]learned that there are numerous factors that influence the performance of standing long jump, including personal genetic quality (height, leg length and weight, etc.), take-off angle, ground-hitting force and aerial technique, particularly the force exertion of knee, ankle and hip joints directly influences the take-off height and coordination capability.

In comparison with foreign counterparts, domestic experts generally insist that keeping the knee angle between 110° and 130° is the most beneficial for volleyball athletes to take off[3] Foreign experts have studied the bouncing ability of world-class volleyball athletes. However, the research results demonstrate that the angles of all sports joints that are most conducive to improving the bouncing height are basically the same, that is, 20°-30° for the trunk angle, so that the knee angle needs to be kept at 120°-130°, while the ankle joint needs to be kept at 80°-90°, but male athletes are generally lower than female athletes[4]

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Table 8: Comparative Analysis of Time-consuming Characteristics in the Post-Buffer Phase ($\bar{x}\pm s$) Unit: s n=6

Team Member	*Shallow Squat*	*Half Squat*	*Deep Squat*
1	*0.08*	*0.12*	*0.24*
2	*0.11*	*0.20*	*0.24*
3	*0.06*	*0.13*	*0.16*
4	*0.15*	*0.20*	*0.20*
5	*0.21*	*0.21*	*0.23*
6	*0.06*	*0.17*	*0.19*
Average Value	*0.1100*	*0.1683*	*0.2075*
Standard Deviation	*0.06058*	*0.04046*	*0.03328*

Table 9: Statistical analysis of Time-consuming Characteristics in the Post-Buffer Phase

Acceleration Immobilization Time	Sum of Squares	df	Mean Square	F	p.
Between Groups	.029	2	.014	6.755	.008
Within Groups	.032	15	.002		
Total	.061	17			

As can be observed from Table 8 and 9 above, there are highly significant differences when F (2,17)=6.755, p=0.008‹0.01. That is, in the squat phase of buffer immobilization, there are significant differences in the impact of shallow squat, half squat and deep squat at different take-off angles on immobilization time. However, through back testing (LSD), it is concluded that there are significant differences in the impact of deep squat for take-off and shallow squat for take-off on the immobilization time in the post-buffer phase. The differences in acceleration in the first half and immobilization in the second half clearly show that deep squat and shallow squat have overall differences in time. On the other hand, it also reveals that properly increasing the buffer time is conducive to increasing the working distance of muscles, making muscles at the most suitable angle, and more conducive to exerting muscle force and increasing the bouncing height.

Table 10: Comparative Analysis of Velocity Characteristics in the Post-Buffer Phase ($\bar{x}\pm s$) n=6

	Shallow Squat	Half Squat	Deep Squat
Average Velocity of Hip	0.558±0.186	0.655±0.137	0.898±0.128
Average Velocity of Knee	0.438±0.103	0.365±0.087	0.288±0.070

Table 11: Statistical analysis of Velocity Characteristics in the Post-Buffer Phase

		Sum of Squares	df	Mean Square	F	p.
Average Velocity of Hip	Between Groups	.368	2	.184	7.963	.004
	Within Groups	.347	15	.023		
	Total	.715	17			
Average Velocity of Knee	Between Groups	.068	2	.034	4.368	.032
	Within Groups	.116	15	.008		
	Total	.183	17			

As can be observed from Table 10 and 11 above, through analysis, it is concluded that there are highly significant differences when F(2,17)=7.963, p=0.004‹0.01; and significant differences when F(2,17)=7.963, p=0.032‹0.05. That is, in the phase of buffer squat immobilization, there are significant differences in the impact of shallow squat, half squat and deep squat on the average velocity of hip and knee during immobilization at different take-off angles. The back testing (LSD) concludes the impact of deep squat for take-off and shallow squat for take-off on the immobilization velocity in the post-buffer phase. The average velocity of hip is highly significantly different between shallow squat and deep squat, while the average velocity of knee is significantly different.

5. Kinematics Analysis of Pedal-Stretch Phase

Table 12: Comparative Analysis of Time Characteristics of Pedal-Stretch ($\bar{x}\pm s$) n=6

	Shallow Squat	Half Squat	Deep Squat
Time	0.082 ±0.027	0.165±0.019	0.247±0.035

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Table 13: Statistical analysis of Time Characteristics of Pedal-Stretch

Pedal-Stretch Time	Sum of Squares	df	Mean Square	F	p.
Between Groups	0.082	2	0.041	52.961	0.01
Within Groups	0.012	15	0.001		
Total	0.093	17			

Table 14: Multiple Comparisons Dependent Variable: LSD of Pedal-Stretch Time

Grouping	Grouping	Mean Difference (I-J)	Std. Error	p.	95% Confidence Interval	
					Lower Bound	Upper Bound
Shallow Squat	Half Squat	-.08333(*)	0.01603	0	-0.1175	-0.0492
	Deep Squat	-.16500(*)	0.01603	0	-0.1992	-0.1308
Half Squat	Shallow Squat	.08333(*)	0.01603	0	0.0492	0.1175
	Deep Squat	-.08167(*)	0.01603	0	-0.1158	-0.0475
Deep Squat	Shallow Squat	.16500(*)	0.01603	0	0.1308	0.1992
	Half Squat	.08167(*)	0.01603	0	0.0475	0.1158
* The mean difference is significant at the .05 level.						

As can be observed from Tables 12 and 13 and 14 above, through analysis, it is concluded that there are highly significant differences when F(2,17)=52.961, p‹0.01. That is, in the pedal-stretch phase of take-off, there are significant differences in the impact of shallow squat, half squat and deep squat on pedal-stretch time at different take-off angles. Through back testing (LSD), it is concluded that there are significant differences in pedal-stretch time between deep squat for take-off and shallow squat for take-off, between deep squat for take-off and half squat for take-off, and between half squat for take-off and shallow squat for take-off. This suggests that the take-off in three different angle ranges bears its own obvious time characteristics, which is not affected by the buffer time and is the decisive factor to determine the bouncing height. This difference will inevitably result in the difference of bouncing height.

Table 15: Comparative Analysis of the Velocity and Acceleration of Hip and Knee Joints in the Pedal-Stretch Phase in Different Angle Ranges ($\bar{x}\pm s$) n=6

	Shallow Squat	Half Squat	Deep Squat
Average Velocity of Hip (m/s)	1.49±0.56	1.40±0.49	1.67±0.33
Maximum Acceleration of Hip (m/s²)	28.16±4.81	20.18±2.35	16.39±2.20
Maximum Angular Acceleration of Hip (°/s²)	4678.32±595.85	3934.65±875.67	2941.87±1208.77
Average Velocity of Knee (m/s)	1.28±0.53	0.90 ±0.18	0.69±0.13
Maximum Acceleration of Knee (m/s²)	34.01±2.70	31.44±3.06	29.99±3.33
Maximum Angular Acceleration of Knee (°/s²)	8303.10±910.79	7407.73±1305.09	5940.91±2548.55

Table 16: Statistical analysis of the Velocity and Acceleration of Hip and Knee Joints in the Pedal-Stretch Phase in Different Angle Ranges

		Sum of Squares	df	Mean Square	F
Average Velocity of Hip during Pedal-Stretch	Between Groups	0.229	2	0.114	0.521
	Within Groups	3.295	15	0.22	
	Total	3.524	17		
Maximum Acceleration of Hip during Pedal-Stretch	Between Groups	433.317	2	216.659	19.345
	Within Groups	167.995	15	11.2	
	Total	601.312	17		
Maximum Angular Acceleration of Hip during Pedal-Stretch	Between Groups	9107809.448	2	4553904.724	5.289
	Within Groups	12914798.87	15	860986.591	
	Total	22022608.32	17		
Average Velocity of Knee of Hip during Pedal-Stretch	Between Groups	1.071	2	0.535	4.882
	Within Groups	1.645	15	0.11	
	Total	2.715	17		

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Maximum Acceleration of Knee during Pedal-Stretch	Between Groups	49.758	2	24.879	2.689
	Within Groups	138.791	15	9.253	
	Total	188.548	17		
Maximum Angular Acceleration of Knee during Pedal-Stretch	Between Groups	17076326.09	2	8538163.042	2.837
	Within Groups	45139593.34	15	3009306.223	
	Total	62215919.43	17		

As can be observed from Tables 15 and 16 above, through statistical description and one-way ANOVA, it is concluded that there are highly significant differences when F(2,17)=19.345, p=0‹0.01; significant differences when F(2,17)=5.289, p=0.018‹0.05; and also significant difference when F(2,17)=4.882, p=0.023‹0.05. That is, in the pedal-stretch phase of take-off, whether it is shallow squat, half squat and deep squat, there are significant differences in the velocity and acceleration of hip and knee joints during pedal-stretch at different take-off angles. Through back testing (LSD), it is concluded that there is a high degree of significance in the maximum acceleration of hip between deep squat for take-off and shallow squat for take-off, and between half squat for take-off and shallow squat for take-off; in the maximum angular acceleration of hip, there are significant differences only between deep squat for take-off and shallow squat for take-off; however, in the average velocity of knee, there are significant differences only between deep squat for take-off and shallow squat for take-off.

6. Kinematics Analysis of Aerial Process

The aerial section is divided into: rising phase and falling phase.

Table 17: Comparative Analysis of the Characteristics of Total Aerial Time (x̄±s) n=6

	Shallow Squat	Half Squat	Deep Squat
Time	0.593±0.067	0.678±0.049	0.718±0.036

Table 18: Statistical analysis of the Characteristics of Total Aerial Time

Aerial Time	Sum of Squares	df	Mean Square	F	p.
Between Groups	.049	2	.024	8.997	.003
Within Groups	.041	15	.003		
Total	.090	17			

As can be observed from Tables 17 and 18 above, it is concluded that there are highly significant differences when F (2,17)=8.997, p=0.003‹0.01. That is, in the take-off and aerial phase, there are significant differences in the aerial time between shallow squat, half squat and deep squat at different take-off angles. Through back testing (LSD), it is concluded that there are significant differences in the aerial time between deep squat for take-off and shallow squat for take-off, and there are also significant differences in the aerial time between half squat for take-off and deep squat for take-off. Such differences are consistent with the velocity differences during aerial and leaving the ground, which also reveals that the starting velocity (off-ground velocity) determines the take-off height and the aerial time, and maintains a high degree of consistency in differences.

Table 19: Comparative Analysis of Initial Velocity Characteristics of Aerial (x̄±s) n=6

	Shallow Squat	Half Squat	Deep Squat
Hip	2.41±0.35	2.97±0.24	3.08±0.42
Knee	2.47±0.40	2.72±0.30	2.49±0.60

Table 20: Statistical analysis of Initial Velocity Characteristics of Aerial

		Sum of Squares	df	Mean Square	F	p.
Initial Velocity of Hip	Between Groups	1.550	2	.775	6.508	.009
	Within Groups	1.787	15	.119		
	Total	3.337	17			
Initial Velocity of Knee	Between Groups	.225	2	.112	.560	.583
	Within Groups	3.010	15	.201		
	Total	3.235	17			

As can be observed from Tables 19 and 20 above, it is concluded that there are highly significant

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differences when F(2,17)=6.508, p=0.009‹0.01. That is, in the initial phase of take-off and aerial, that is, the off-ground phase, there are significant differences in the take-off and off-ground velocity between shallow squat, half squat and deep squat at different take-off angles. Through back testing (LSD), it is concluded that there are highly significant differences in the initial aerial velocity between deep squat for take-off and shallow squat for take-off; also significant differences in the initial aerial velocity between half squat for take-off and shallow squat for take-off, not highly significant. Such differences are consistent with those with the aerial height, which also reveals that the starting velocity (off-ground velocity) determines the take-off height.

Table 21: Comparative Analysis of the Characteristics of Changes in Aerial Height (x̄±s) n=6

	Shallow Squat	Half Squat	Deep Squat
Height	0.40±0.12	0.57±0.07	0.64±0.07

Table 22: Statistical analysis of the Characteristics of Changes in Aerial Height

Aerial Height	Sum of Squares	df	Mean Square	F	p.
Between Groups	.196	2	.098	11.709	.001
Within Groups	.126	15	.008		
Total	.322	17			

As can be observed from Tables 21and 22 above,it is concluded that there are highly significant differences when F(2,17)=11.709, p=0.001‹0.01. That is, there are significant differences in aerial height between shallow squat, half squat and deep squat at different take-off angles. However, after back testing (LSD), it is concluded that there are highly significant differences in aerial height between deep squat for take-off and shallow squat for take-off; and also highly significant differences in aerial height between half squat for take-off and shallow squat for take-off.

7. Kinematics Analysis of Landing Phase

Table 23: Comparative Analysis of Time-Consuming Characteristics in Landing and Buffer Phase (x̄±s) n=6

	Shallow Squat	Half Squat	Deep Squat
Time	0.10±0.03	0.14±0.04	0.16±0.05

Table 24: Statistical analysis of Time-Consuming Characteristics in Landing and Buffer Phase

Landing and Buffer Time	Sum of Squares	df	Mean Square	F	p.
Between Groups	.010	2	.005	3.200	.070
Within Groups	.025	15	.002		
Total	.035	17			

As can be observed from Tables 23 and 24 above, there are no significant differences in buffer time. This also demonstrates that the athletes have their own characteristics when they fall to the ground. During the experiment, no requirement was imposed on the athletes to land in accordance with the rhythm of competition; thus, the analysis of their movements at the moment of landing was confined to the lowest point, allowing for a more vivid portrayal of their individual characteristics. In studying the kinematic features of the landing phase, volleyball displays relatively fewer instances, whereas basketball, badminton, and tennis present a higher prevalence, which holds significant implications for the prevention of sports-related injuries.

Table 25: Comparative Analysis of Angle Characteristics at the End of Landing and Buffer (x̄±s) n=6

	Shallow Squat	Half Squat	Deep Squat
Hip Angle	148.37±15.17	137.23±16.65	119.91±26.23
Knee Angle	127.53±14.74	110.74±12.05	100.55±30.05

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Table 26: Statistical analysis of Angle Characteristics at the End of Landing and Buffe

		Sum of Squares	df	Mean Square	F	p.
Landing Hip Angle	Between Groups	2467.688	2	1233.844	3.097	.075
	Within Groups	5976.601	15	398.440		
	Total	8444.288	17			
Landing Knee Angle	Between Groups	2227.223	2	1113.612	2.639	.104
	Within Groups	6329.295	15	421.953		
	Total	8556.518	17			

As can be observed from Tables 25 and 26 above suggest that at the end of the landing and immobilization phase, there are no significant differences between the hip and knee angles, lacking statistical significance. This finding indicates that athletes habitually adopt specific angles and movements during the landing and buffer phase, which, at this juncture, no longer contribute to height or velocity but are primarily related to the risk of sports-related injuries.

Consequently, research focus on the joints of the knee, hip, and ankle during landing has shifted away from the pursuit of height and velocity; instead, the emphasis has shifted towards understanding the relationship between movement and injury. Domestically, there is a relative scarcity of studies examining joint angles and peak force during landing, whereas there is a greater abundance of such research abroad. Bing Yu et al. have demonstrated that increasing the degree of angular flexion of knee joint does not necessarily equate to a soft landing[5] Conversely, De Vita and Skelly have presented contrasting views, asserting that, in experiments comparing soft landings with no buffer, increasing the flexion angle of knee joint can effectively reduce the maximum ground impact force. They further highlighted that, during straight-leg landings, the ankle joint absorbs a disproportionate amount of energy, whereas during soft landings, the hip and knee joints absorb more energy. Moreover, they observed that with increasing height, the work done by the flexor group of ankle joint does not increase significantly, whereas the work done by the hip and knee joints markedly increases[6] In studies investigating the relationship between the angle of knee joint during landing and the risk of injury, Stacoff and his coworkers held that the more extended the knee joint is during landing, the greater the joint angle, necessitating increased flexion of the knee joint, which in turn heightens tension in the patellar tendon, potentially leading to patellar aponeurositis. Similarly, David, et al. found that a greater flexion angle of knee joint is a significant predictor of patellar aponeurositis among elite volleyball athletes[7].

8. Conclusion

There are significant differences at the time of buffer and immobilization among the three take-off modes of volleyball athletes in the process of blocking, namely, shallow squat, half squat and deep squat during squat ($p=0.008<0.01$), and significant differences in the maximum velocity of hip in the pre-buffer phase ($p=0.006<0.01$) and the buffer immobilization phase ($p=0.004<0.01$); in pedal-stretch phase of take-off, the effects of shallow squat, half squat and deep squat on pedal-stretch time are significantly different ($p<0.01$) at different take-off angles, which is corresponding to the effects of velocity and acceleration of hip and knee joints during pedal-stretch ($p=0.023<0.05$); deep squat for take-off, shallow squat for take-off and half squat for take-off also show significant differences in aerial time ($p=0.003<0.01$); deep squat for take-off and shallow squat for take-off have highly significant differences in the initial aerial velocity, and half squat for take-off and shallow squat for take-off also show significant differences in the initial aerial velocity ($p=0.003<0.01$);

There are also highly significant differences in aerial height among shallow squat for take-off, deep squat for take-off and half squat for take-off ($p=0.001<0.01$). This consistency in the differences of aerial time, aerial velocity and aerial height also reveals that the starting velocity (off-ground velocity) determines the take-off height and aerial time, and maintains a high degree of consistency in differences.

This demonstrates that throughout the entire movement, the hip plays a crucial role as a pivotal bond. It is essential to strengthen the hip force through regular training to maintain the stability of the hip joint. Simultaneously, it is important to enhance the force and flexibility of the knee and ankle

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joints through targeted exercises.

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