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Evaluation of the Team Offensive Performance in Volleyball using Three Dimensional Analysis*

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I. Introduction

Enhancing the sports performance has been a major issue of the sport science. In sport biomechanics, the human movement analysis technique, which was traditionally based on cinematography, has been utilized to investigate sports performance problems. This process includes recording visual images of body parts in motion on to a cine film or videotape at high speed, then later analyzing the stored image to obtain numeric space-time information about body segments. The data are manipulated to reveal the movement patterns of the body or to determine the kinematics of the body parts, the joint forces and moments, or the mechanical energy flow between the body segments depending upon the researcher's point of view of the sports performance.

The topics in human movement analysis have become broad, but it has been bounded to a certain direction because of its inherent limitation in cinematographic medium. It can be pointed out that most of the sports skills investigated using a cinematographic method were executed within relatively short duration. Frequently investigated sports skills are the high jump and throwing motions in the fields events, gymnastics vaults, golf swing, volleyball spike, tennis serve or ground stroke, and one or a few steps of locomotion.

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These rather selective sports skills have been analyzed in sport biomechanics because their short duration avoided the high costs for 16 mm film and for the time commitment required in the data-generating process of manual digitizing. However, with the advent of video motion analysis systems, this limitation is no longer a problem, although video systems suffer from different shortcomings.

Certain sports skills especially those of ball games consist of a series of distinctive movement patterns such as serve, receive, ground stroke, volley, smash, and lob in tennis or serve, pass, set, spike, and block in volleyball. Regardless of the number of players in a game, whether it is an individual or a team game, there exists a biomechanical cause and result relationship between the consecutive movements to be performed during a game. It is absolutely necessary to understand the whole interaction mechanisms between different skills performed in series whenever the outcome of a game is to be predicted.

The sports biomechanical study on this kind of transition play has rarely been found except for that of Eom and Schutz (1992). Although a video recording system was utilized to analyze volleyball games, only the speed of the served ball was quantitatively estimated (You, Kim, Kwak, & Youn, 1988). You and co-researchers examined the frequencies of the offensive tactics performed by each of the six national teams that participated in the 3rd FIVB Seoul International Men's Volleyball Cup Competition held in November, 1987.

Eom and Schutz (1992) specifically utilized the video records taken during the 3rd FIVB Seoul International Men's Volleyball Cup Competition held in 1987 to investigate the pass to set, set to spike, or pass to spike through log-linear analysis. They found that skills are significantly influenced by the quality of preceding skills. However, neither You *et al.* (1987) nor Eom and Schutz (1992) included reports on how the skills were actually performed.

The purpose of this study was to investigate the relationship between the transition play of volleyball game and the outcome of the play from the kinematical point of view.

Ⅱ. Method

The entire men's final match between the H Team and the L Team in the Korean Volleyball '95 Super League Competition held in 1995 was video taped for the three dimensional analysis. Each of eight range poles of 3 m long was set vertically on the four corners and on the sports on sidelines 4.5 m away from each corner toward the net. The poles were recorded by two video cameras for 3-D analysis. The two S-VHS video cameras were set on the top level of the spectator-seating area in the Gymnasium. The viewing angle between the cameras was approximately 90 degree, as shown in Fig. 1.

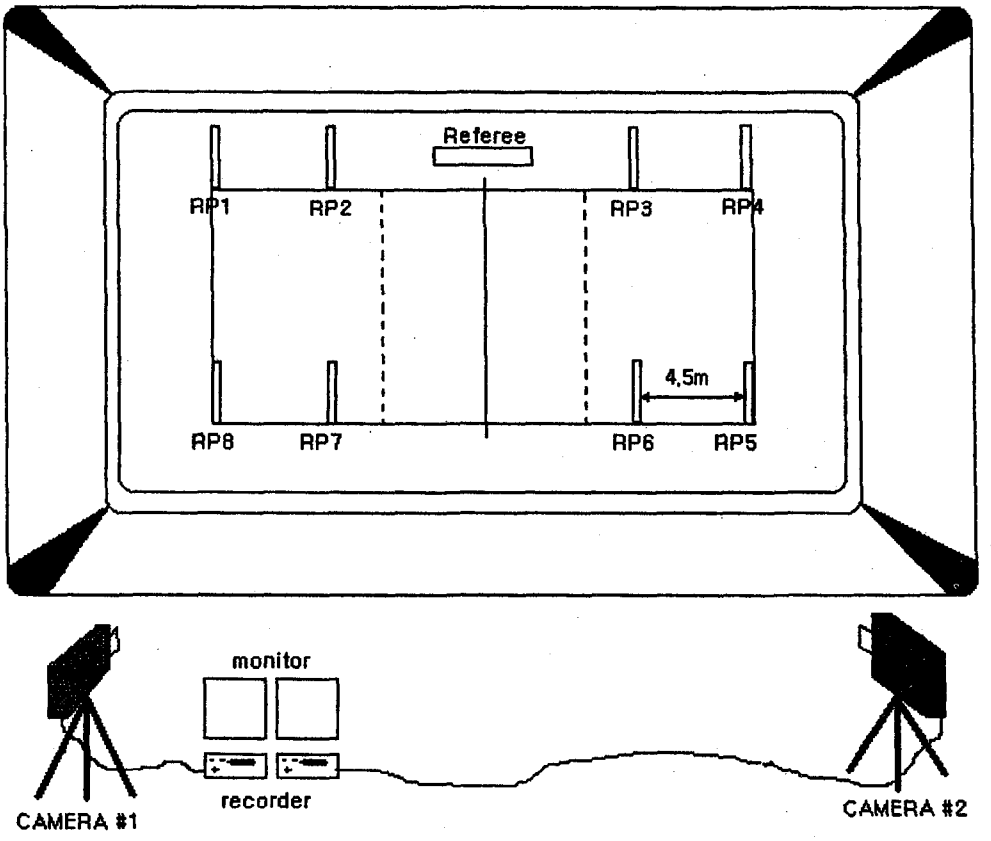


Fig. 1. Schematic Drawing of the Camera and Range Pole Locations

1. Data Collection

General guidelines for the direct linear transformation (DLT) (Walton, 1981) 3-D analysis technique were followed to generate the DLT parameters. Twenty-four known coordinates on the range poles were used in the process. Six body landmarks including two hands, two shoulder joints, and two feet from each of the offensive players of both teams and one from the ball were video digitized with the S-VHS Panasonic D-5100 video player and DT-2861 frame grabber equipped computer system.

Each digitizing session started from the view of ten frames before that of every reception and ended at ten frames after the spike event. This digitizing procedure was repeated for every other frame. However, the temporal data were determined by counting every frame in the defined interval.

2. Data Analysis

The serve reception position, setter's initial ready position, actual ball contact position during set, ball contact position for spike, and the blocker's hand positions were used to evaluate the performance of the players. In order to determine the receiver's pass performance, the distance between the target which was set 2.5 m above the setter's initial ready position and the actual ball contact position to set the ball (setter-moving distance) was measured.

The setter's setting performance was assessed indirectly by determining the open area which was defined as the vertical distance from the pass target to the actual ball contact height during setting (ball contact height relative to 2.5 m), and the area on the opponent's court seen from the spiked position (open area). Both of the assistant attackers' combined performances were determined by calculating the distances between the two players and the blockers assigned for each of them (assistant-spiker to blocker distance).

Finally, logistic regression was applied to investigate the influences of serve reception to setting and setting to spiking transition play on the outcome of the play (Eom and Schutz, 1992). The SPSS statistical program was used and the significance level was set at 0.1. The outcome of the play means winning a point or service (side-out), or failure of the spike.

The logit, which was used as the dependent variable for the logistic

regression, is defined as follows:

$$\text{Logit} = \text{Log}_e \{P / (1-P)\}$$

when P is the probability that a spike is successful.

Ⅲ. Results and Discussion

The men's final match for the Korean Volleyball '95 Super League Competition was won by H Team by 3 to 0 sets over L Team. The major skills performed by both teams are listed in Table 1.

Table 1. The Main Skills and Their Frequencies Performed by the Two Teams During the Three Sets

	H Team	L Team
No. of total offensive spike (T.O.S)	144	155
Open spike succeeded (% of attempted)	33(55.9)	29(40.8)
/ attempted (% of T.O.S)	/ 59(40)	/71(45.8)
A quick spike succeeded (% of attempted)	25(71.4)	13(59.0)
/ attempted (% of T.O.S)	/ 35(24.3)	/22(14.1)
B quick spike succeeded (% of attempted)	8(57.1)	6(40.1)
/ attempted (% of T.O.S)	/ 14(9.7)	/15(9.6)
Back attack succeeded (% of attempted)	5(21.7)	6(40.0)
/ attempted (% of T.O.S)	/23(15.9)	/19(12.2)
Blocking points / side out	20 / 2	8 / 3

It seems that there are differences in the way of executing offensive skills. While H Team distributed the offensive skills from open spiking to A quick as two to one ratio, L Team performed the open spiking more frequently than A quick compared to H Team. The success ratios for those skills performed by the two teams were noticeably different. However, the determinant of the game outcome would be the points earn by the blocking performed by H Team. H

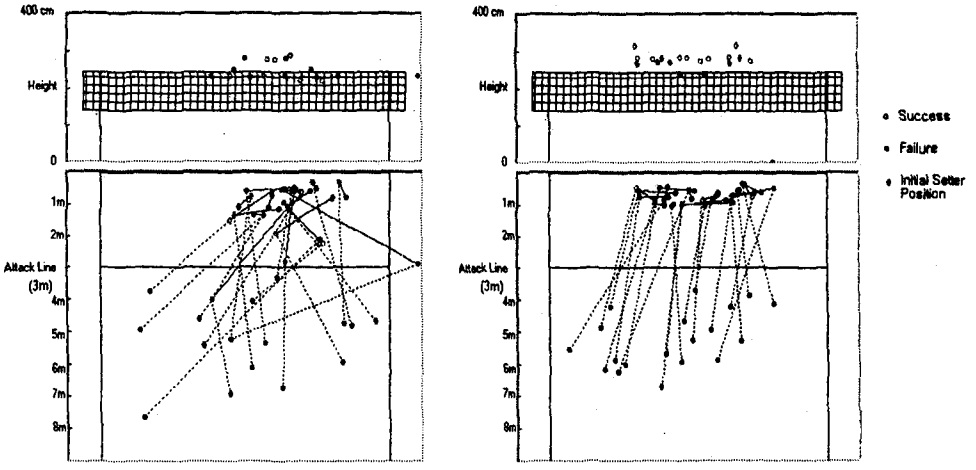
Team scored 20 points out of total 45 points with the blocking. This result would indicate that either the sets performed by L Team were predictable to H Team blockers or serve reception and pass of L Team were not good enough to produce diverse offensive skills.

Although the ratio of performed open spikes relative to all cases of offensive maneuver by H Team was somewhat small compared to those of highly ranked national teams reported by You et al. (1988), the success ratio was close to those of the national teams ranked within the top sixth place in the world. It was also possible to point out that the high success ratio of the A quick spike achieved by H Team would indicate that the L Team could be distracted by the setter of H Team.

The kinematic description of the pass and set skills for both of the open spikes and A quick spikes were made based on part of 130 times of open spikes and 57 times of A quick spikes, respectively. Twenty-two open spikes which include 13 failed attempts and 9 successful attempts were selected from the first and second sets. Nineteen A quick spikes cases which include 9 failed attempts and 10 successful attempts were also selected from the first and the second sets. The means and standard deviations of the setter moving distances during passing, ball contact height at the beginning of setting (see Fig. 2), assistant-spikers to blockers distance at the moment of spiking were calculated for open spikes and A quick spikes (Table 2).

Table 2. Means and Standard Deviations of the Performance Evaluation Criteria for the Successful and Failed Spikes

	Open Spikes (n=22)		A quick spikes (n=19)	
	Success (n=9)	Fail (n=13)	Success (n=10)	Fail (n=9)
Setter-moving distance (cm)	88(75)	189(155)	70(36)	95(56)
Ball contact height relative	8(26)	11(43)	30(19)	29(23)
to 2.5m high pass target (cm)	3.75(0.96)	6.14(8.19)	5.01(0.56)	4.69(0.73)
Assistant spiker to blocker	37.3(20.4)	29.2(21.5)	52.0(10.5)	43.5(17.2)
Distance (m)				
Open area (m^2)				
Ball contact height during spike (cm)	315(7)	316(11)	306(7)	302(8)
Ball contact position from the	115(44)	106(52)	61(13)	53(20)
Net during spike (cm)				



Open spikes A quick spikes

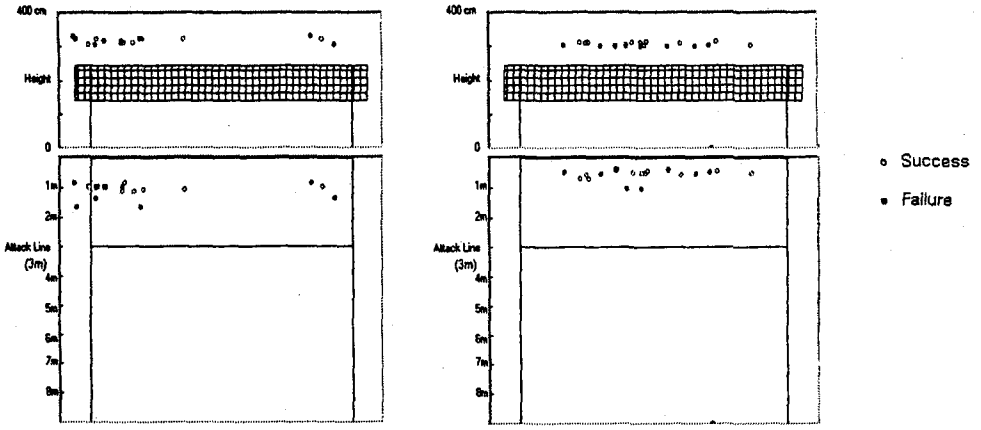
Fig. 2. Set Positions and Setter Moving Distance (solid line) for Open Spikes and A Quick Spike

It was expected that the setter's moving distance would be shorter, the ball contact height relative to the 2.5 m high pass target would be closer, the assistant-spiker to blocker distance would be shorter, and the open area would be smaller for a highly skilled group than a low skilled group.

Table 2. presents the expected patterns between successful and failed trials for all the performance evaluation criteria except for the assistant spiker to blocker distance measured for the A quick spike. The finding that the distance to blocker from assistant-spiker is longer for the successful A quick spikes than the failed may mean that for A quick spikes the execution time is too short to distract blockers' attention to the assistant-spiker. When a spiker hits the ball, it is expected for the rest of offensive players as if either one of them is a real attacker. However, when a team executed the A quick spike it took about 0.7 second from the setting to the completion of the spike. Because of this they would not have enough time to move to cover for an assigned offensive player.

The results of the ball contact position measure showed that, whether the spike is successful or unsuccessful, the spikers hit the ball approximately 315 cm high from the floor when performing open spike (see Fig. 3). This may

indicate that the setter's setting ability contributes to success when the blockers do not expect the set. This result shows that blocking timing and individual capability of the offensive players are related to the outcome of the offense.



Open spikes A quick spikes

Fig. 3. Ball-hitting-positions for Open Spikes and A Quick Spikes.

It was found that the average ball-hitting-position was around 110 cm away from the net for the open spikes and around 57 cm away from the net when performed A quick spikes (see Fig. 3). Although Kao, Sellens and Stevenson (1994) argued that the optimal ball contact position to avoid blocking is at 2 m away from the net, the players investigated in this study hit the open spike closer to the net in real competition. When a spiker performs the back attack, the ball hitting position can be located at around 2 m away from the net. It is easy to avoid blocking when performing a back attack. However, the open area to be seen behind the block will be drastically reduced (see Fig. 4).

Table 3 presents the logistic regression results for open spike cases. The results show that the logit is explained only by one predictor, setter-moving distance (β = -0.0097), with =0.1. This means that, with setter-moving distance increased by 1 cm, the logit is decreased by 0.0097. This finding also implies that the probability for a successful spike is reduced. Namely, the farther the

setter moves to receive the ball to set, the higher is the chance that the spike would fail. Thus, the receiver should pass the ball to the setter more accurately to lead to a successful spike.

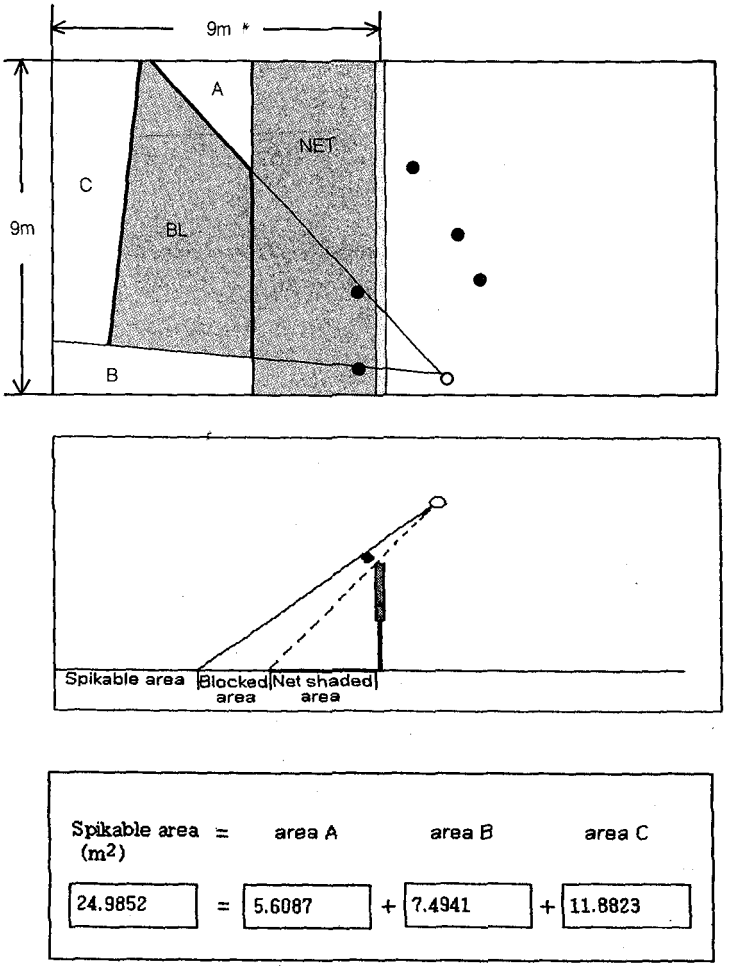


Fig. 4. Spikable Open Area Seen Beside and Over the Blockers' Hands.

However, it should be noted that the relationship between the setter-moving distance and the probability for a successful spike is not linear because the relationship between the logit and the probability for a successful spike is characterized by an S-shape. The effect on the probability for success is

different depending on the logit. The probability change is more dramatic with the logit at the middle level of the whole range than at the low and high level. The logit can be converted to the actual probability (see Fig. 5) using the following formula revised from the definition of the logit:

Probability (Success)= e^{logit} / (1 + e^{logit}).

All the other variables (ball contact height relative to 2.5 m, assistant-spiker to blocker distance, and open area) were not statistically significant.

Table 3. Logistic Regression Results

Variable	B	S. E.	Wald	Df	Sig	R	Exp (B)
HORIDIST	-.0097	.0055	3.1162	1	.0775	-.1936	.9904
VERTDIST	-.0154	.0162	.9061	1	.3412	.0000	.9847
BLCKDIST	-.1115	.1696	.4322	1	.5109	.0000	.8945
AREA	.0238	.0266	.7997	1	.3712	.0000	1.0241
Constant	.7689	1.4132	.2961	1	.5864		

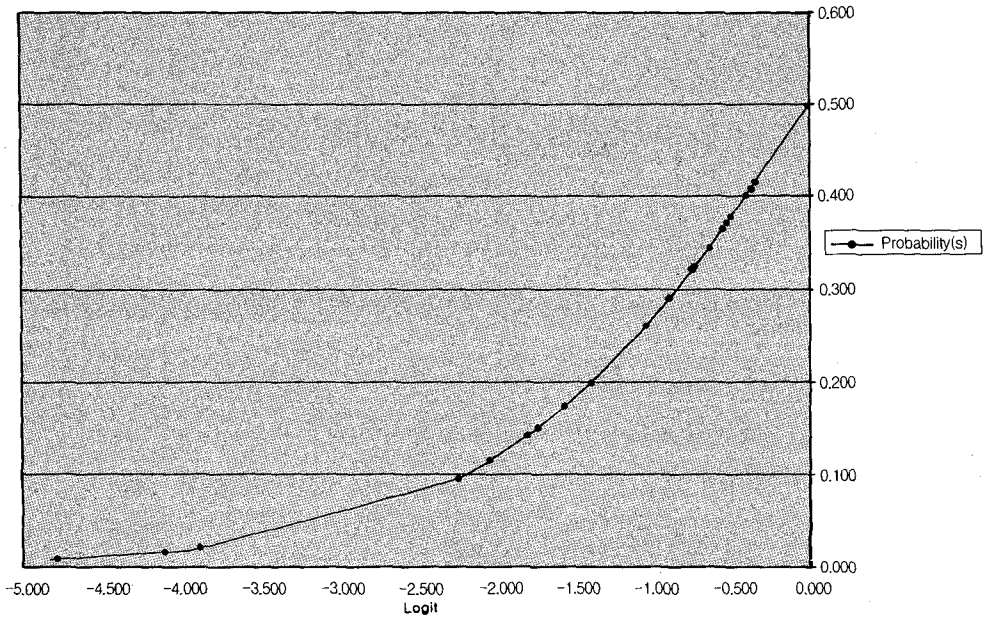


Fig. 5. Probability of Winning Point vs. Setter-Moving Distance Converted to Logit

For A-quick spike, the logistic regression results indicate that no variable of the four predictors is significant in explaining the variance of the logit.

Ⅳ. Conclusion

Based on limited cases of offensive team plays considered in this study, the service reception skill is closely related to winning or losing a point when a team executes an open spike

This study had several limitations. First, the number of data sets may have been too small for the generalization of the results, as only 22 cases were analyzed for open spike and 19 cases for the A-quick. Second, the digitized data contained relatively large uncertainties due to the cameras positioning far from the players with relatively small images for analysis. Third, alternative variables were not examined. These might include a variable regarding the spike impact such as the relative distance of the spiker to the ball at the time of contact.

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<초 록>

3차원 영상분석법을 이용한 배구 경기의 팀 공격 수행 능력 평가

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본 연구는 배구 경기의 경기 수행 능력을 향상시키기 위해 선수들간의 상대적 움직임과 진형을 거시적으로 살펴보고, 동시에 공격과 수비에 가담하는 선수들의 동작을 미시적으로 관찰하는데 그 목적이 있다. 이를 위해 성인 남자 경기를 대상으로 비디오 카메라를 이용한 3차원 영상분석을 실시하였다. DLT방식을 이용하여 3차원 좌표를 계산하였고, 각 변인들의 계산을 위해 비쥬얼 베이직 5.0으로 프로그래밍하였다.

경기결과 H 팀이 L 팀에게 3:0으로 승리하였는데, H 팀은 주로 오픈 공격 (41%)과 A 속공 (24%)을, L 팀은 오픈 공격을 시도하는 것으로 나타났다. 공격의 성공, 실패를 결정짓는 요인으로는 두 팀 모두 블로킹을 들 수 있는데, H 팀은 전체 45득점 중 20득점이 블로킹에 의한 점수로 나타났다. 이는 L 팀의 서브 리시브와 세트가 H 팀의 블로커들에게 예측되었기 때문으로 사료된다.

22회의 오픈공격 (성공 : 9, 실패 : 13)과 19회의 A 속공 (성공 : 10, 실패 : 9)에 대해 패스시 세터 이동거리, 세트시 볼을 접촉한 높이, 스파이크시 보조공격수와 블로커들과의 거리, 스파이크시 오픈된 공격 면적 등을 분석하였다. 오픈 공격시 세터의 이동거리는 성공시 88±75 cm, 실패시 189±155 cm로 나타났고, A 속공시에는 각각 70±36 cm, 95±56 cm로 나타났다. 볼을 접촉한 높이는 네트 높이 위의 일정 지점 (250 cm)을 기준으로 오픈 공격시 성공 8±26 cm, 실패 11±43 cm로 나타났고, A 속공시에는 각각 30±19 cm, 29±23 cm로 나타났다. 스파이크시 보조공격수와 블로커와의 거리는 오픈 공격시 성공 3.75±0.96 m, 실패 6.14±8.19 m로 나타났고, A 속공시에는 각각 5.01±0.56 m, 4.69±0.73 m로 나타났다. 스파이크시 오픈된 공격 면적은 오픈 공격시 성공 37.3±20.4 m^2, 실패 29.2±21.5 m^2로 나타났고, A 속공시에는 각각 52.0±10.5 m^2, 43.5±17.2 m^2 로 나타났다. 또한 스파이크

시 볼과의 접촉 높이는 오픈공격시 성공 315±7 cm, 실패 316±11 cm로 나타났고, A 속공시에는 각각 306±7 cm, 302±6 cm로 나타났으며, 네트로부터 떨어진 거리는 오픈공격시 성공 115±44 cm, 실패 106±52 cm로 나타났고, A 속공시에는 각각 61±13 cm, 53±20 cm로 나타났다.

한편 이들 변인들과 공격 수행 결과간의 관계를 알아보기 위해 로지스틱 회귀분석을 실시한 결과 세터의 이동 거리 만이 통계적으로 유의하게 나타났다. 이는 세터가 세트를 위해 많이 이동하게 될수록 공격 성공률이 감소하는 것을 의미하는 것으로 정확한 리시브가 공격 성공을 위해 중요한 요인임을 알 수 있다. 그러나 서브리시브가 완벽하다 하더라도 그것이 공격의 성공, 실패를 예측하는 정도는 50% 밖에는 되지 않는 것으로 보아 공격수의 기능이 공격 성공 여부의 중요한 결정 요인이라는 것을 추정할 수 있다.

다른 요인들도 많은 영향들을 끼치리라 생각되었는데, 기대한 바와 다르게 나타난 이유는 첫째, 결과를 일반화 하기 위한 자료수의 부족과 둘째, 카메라 한대가 코트 전체를 커버함으로써 발생하는 해상도의 한계를 들 수 있으며, 마지막으로 스파이크시 공격수의 관점에서 본 스파이크 위치에 대한 상대적인 거리 등과 같은 대체 변인들이 예시되었어야 한다는 점이다. 따라서 이러한 요인들을 고려한 후속 연구의 필요성이 요구된다.