TOPICS IN EXERCISE SCIENCE AND KINESIOLOGY

Process of Science

Influence of the Step Number of the Approach Run on the Jumping Kinematics in Volleyball Spike Jumps

SABURO NISHIMURA[1], YOSHINORI KINOMURA[2], YUJI OSHIMA[3], HARUHI KATAOKA[4], SHUHEI LIDA[5], and SHOHEI YOKOZAWA[6]

[1]Aichi University of Education, Aichi, JAPAN; [2]Aichi Toho University, Aichi, JAPAN; [3]Kurume University, Fukuoka, JAPAN; [4]Sendai University, Miyagi, JAPAN; [5]Kokushikan University, Tokyo, JAPAN; [6]Heisei International University, Saitama, JAPAN

ABSTRACT

Topics in Exercise Science and Kinesiology Volume 4: Issue 1, Article 15, 2023. In volleyball, the approach run serves as a strategy to execute a spike from an elevated striking position. Nevertheless, the influence of the step number of the approach run on the jumping kinematics in spike jumps is unclear. Therefore, this investigation aims to clarify the impact of varying step numbers within the approach run on jumping kinematics. Seven female volleyball athletes were tasked with executing spike jumps, employing 2 and 3-step approach runs. These trials were recorded using high-speed cameras and digitized, and then the kinematics of the 2 and 3-step trials were compared. The findings of this study unveiled that, in the 3-step trial with higher horizontal velocity, the center of gravity was upheld at an elevated level, thereby curtailing the vertical displacement of the center of gravity from the last step before the takeoff to the takeoff. Within the 2-step trial, a notable deceleration of horizontal velocity in the first half of the takeoff was virtually absent. However, the 3-step trial with higher horizontal velocity entailed more flexion of the dominant knee joint to decelerate the horizontal velocity during the first half. Furthermore, the 3-step trial entails a swifter extension of the hip, knee, and ankle joints of the non-dominant leg. This accelerated extension likely contributes to an augmented vertical velocity at the foot release of the takeoff.

KEY WORDS: Female volleyball athlete, dominant leg, non-dominant leg, joint angle, joint angular velocity

INTRODUCTION

In volleyball, since a substantial portion of points are scored through spikes, the success or failure of such spiking has a significant impact on the outcome of a match. To heighten the spike success rate, executing spikes from an elevated striking position is effective. One technique for achieving this is the approach run. Previous research has identified significant positive correlations between horizontal velocity during the approach run and jump height (6, 9), and increasing the step number of the approach run can enhance horizontal velocity during the approach run. Nevertheless, how jumping kinematics vary by incrementing the step number of the approach run remains unclear. Consequently, this study aimed to clarify the influence of varying step numbers within the approach run on jumping kinematics.

METHODS

Seven female volleyball athletes (height: 173.4 ± 4.0 cm, weight: 62.3 ± 4.7 kg, age: 20.7 ± 1.1 years, training experience: 10.9 ± 1.5 years, position: four outside hitters (all right-handed), three opposites (two right-handed and one left-handed)) took part in this study. The sample size was estimated by a priori power analysis using the G*Power software (Version 3.1.9.7, Universität Kiel, Germany). The possible effect size (d) of 1.2 for jump height was obtained in the preliminary experiment. The sample size for the present study was calculated based on an effect size (d) of 1.2, an alpha level of 0.05, a power (1-β) of 0.80, and a one-tailed test. It was estimated that at least 7 participants per group were necessary. The participants were members of the Kanto University Volleyball League Division 1 team in Japan. This research was conducted with the approval of the Ethical Committee (Reception No. 19009) established at the author's institution and in full accordance with the ethical standards outlined in the International Journal of Exercise Science (8). In the experimental trials, participants were required to execute the spike jumps. They jumped and spiked a ball which the setter did not set, but underhand threw from the setter's position, following the 2 and 3-step approach run. The definitions of 2 and 3-step trials are indicated in Figure 1. The underhand throw was performed by the same setter. The participants were given instructions to jump to their maximum height and spike the ball with the highest possible force to the middle back of the opponent's court. Figure 2 shows the schematic diagram of data collection. To familiarize themselves with the experimental trials, they practiced these trials one week before data collection. They performed the trials until achieving three successful attempts for each step trial. A successful attempt was judged by experienced coaches affiliated with the team. The criteria were whether a maximum jump height and powerful strike were achieved. The four high-speed cameras (EXILIM EX-100PRO, CASIO Inc.) were used to record the experimental trials. The recording speed was set to 240 fps, with an exposure time of 1/1000 second. Before commencing data collection, calibration was conducted to facilitate accurate real-length conversion using the 3D DLT method. Utilizing Frame-DIAS 6 (DKH Inc.), 23 body landmarks were manually digitized at 120 fps. This digitization spanned from 10 frames before the dominant foot release of the last step before the takeoff (referred to as the last step), to 10 frames after spiking the ball in the flight phase. Subsequently, the 3D DLT method was applied, yielding the three-dimensional coordinates of the body landmarks. The mean reconstruction errors for these coordinates were 0.5 cm on the X-axis, 0.6 cm on the Y-axis, and 0.2 cm on the Z-axis. From the acquired three-dimensional coordinates, the subsequent kinematic variables were computed: jump height (the maximum center of gravity (referred to as CG) height during the flight phase minus the CG height at the non-dominant foot release), relative CG height (CG height / body height), horizontal velocity of CG (referred to as horizontal velocity), vertical velocity of CG (referred to as vertical velocity), hip flexion-extension angle, knee flexion-extension angle, ankle dorsiflexion-plantarflexion angle, trunk forward-backward tilt angle, thigh forward-backward tilt angle, shank forward-backward tilt angle, CG angle (This angle exists on a plane perpendicular to the ground and encompasses the CG coordinates at the dominant foot touchdown and non-dominant foot release of the takeoff. It signifies the angle between the horizontal line and the line connecting the CG and the dominant thenar at the midpoint of the support phase.) (Figure 3). The first half of the takeoff spans from the dominant foot touchdown to the non-dominant foot touchdown, while the second half of the takeoff extends from the non-dominant foot touchdown to the non-dominant foot release (Figure 1). The calculation of CG was executed utilizing the body segment inertial parameters according to Ae (1996). Wilcoxon signed-rank test was employed to compare the values of each variable of 2 and 3-step trials. The significance level was set at less than 5%.

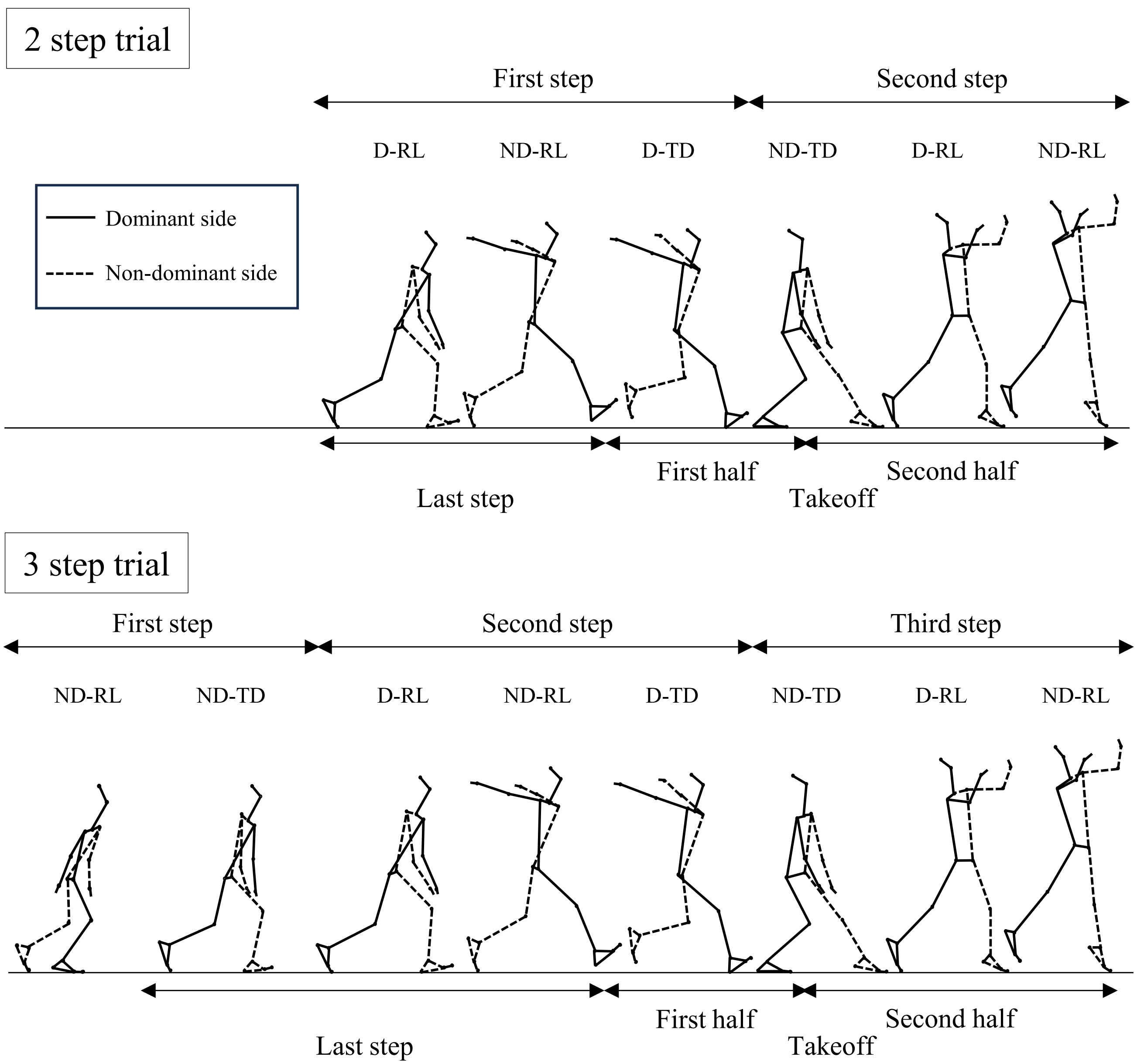

Figure 1. The definitions of the 2 and 3-step trials and step phase.

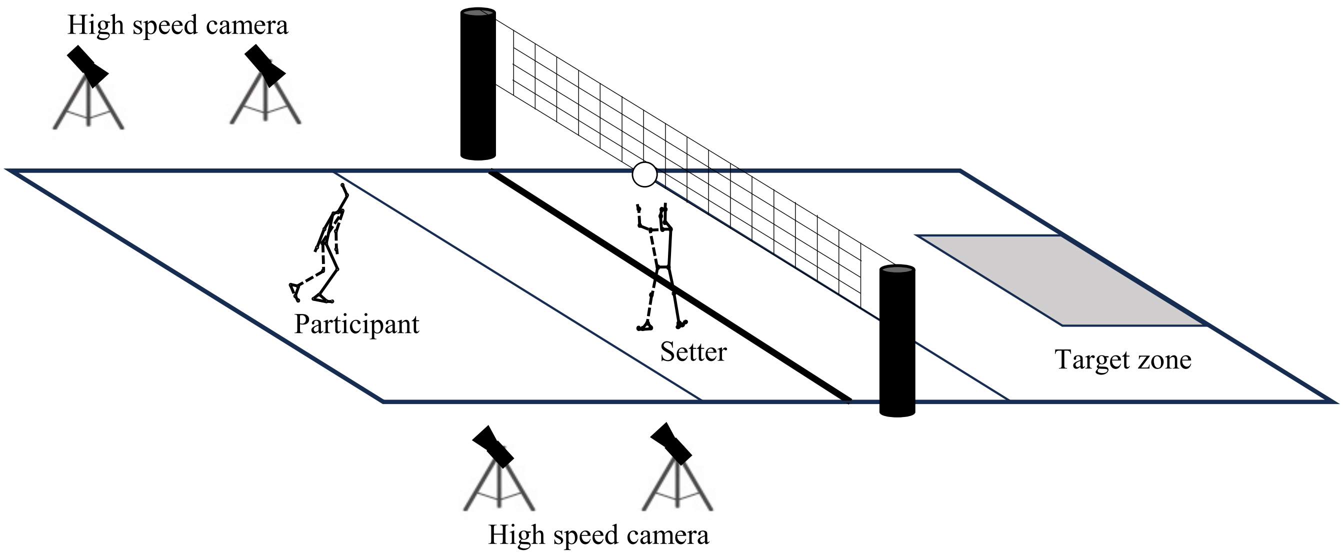

Figure 2. The schematic diagram of data collection.

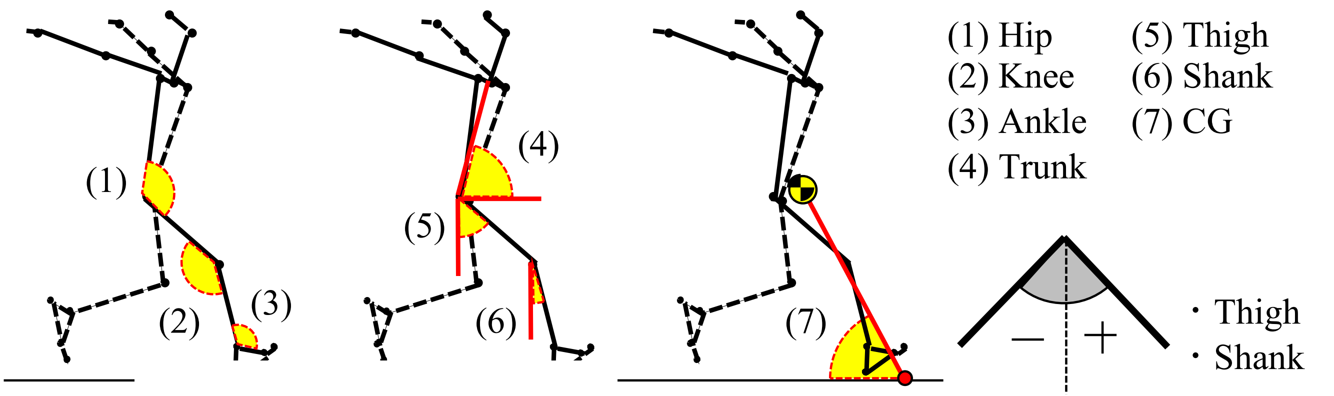

Figure 3. The definition of joint and segment angles.

Points of Application

Increasing the step number enhances the horizontal velocity and jump height.

Jump height was significantly larger in the 3-step trial compared to the 2-step trial (Table 1). A previous study has indicated that among male volleyball athletes, increasing the step number enhanced jump height, while the step number had no effect on jump height for female volleyball athletes (7). Nevertheless, this study's findings contradict the aforementioned research, suggesting that the step number of the approach run does impact jump height for female volleyball athletes. Furthermore, an increment of horizontal velocity from the dominant foot release of the last step to the non-dominant foot touchdown of the takeoff was found as the step number increased (Table 1). However, the influence of horizontal velocity on jump height presents inconsistencies within previous studies. For male volleyball athletes executing 3-step trials, a significant correlation between horizontal velocity and jump height was found (9). Conversely, among female volleyball athletes, one study (6) reported a significant correlation between these two variables in the 2-step trial, while another study (5) found no significant correlation in the 3-step trial. Our findings suggested that at least enhancing horizontal velocity by incrementing the step number could lead to a larger jump height among female athletes.

Table 1. Comparison of kinematic variables relating to CG.

Variable			2 step		3 step		Wilcoxon signed-rank		
			M	SD	M	SD	p		ES (r)
Jump height			40.7	2.5	44.6	2.3	0.018	*	0.91
Relative CG height	LS	D-RL	0.480	0.014	0.490	0.017	0.043	*	0.76
		Min	0.467	0.009	0.472	0.014	0.091	†	0.65
		ND-RL	0.510	0.017	0.512	0.019	0.499		0.18
	TO	D-TD	0.503	0.017	0.503	0.017	0.735		0.06
		Min	0.440	0.010	0.444	0.008	0.063	†	0.63
		ND-TD	0.446	0.012	0.451	0.011	0.063	†	0.68
		ND-RL	0.656	0.014	0.652	0.012	0.398		0.44
	TOΔ	D-TD - Min	-0.063	0.014	-0.059	0.015	0.176		0.56
		Min - ND-RL	0.215	0.018	0.208	0.017	0.028	*	0.74
Horizontal velocity	LS	D-RL	1.78	0.24	2.50	0.30	0.018	*	0.98
		ND-RL	2.98	0.10	3.47	0.14	0.018	*	0.97
	TO	D-TD	2.95	0.09	3.48	0.10	0.018	*	0.98
		ND-TD	2.92	0.22	3.18	0.29	0.043	*	0.76
		ND-RL	1.50	0.26	1.65	0.28	0.176		0.42
	TOΔ	1st half	-0.03	0.26	-0.30	0.28	0.028	*	0.76
		2nd half	-1.42	0.27	-1.53	0.24	0.128		0.56
		All	-1.45	0.31	-1.84	0.31	0.028	*	0.78
Vertical velocity	LS	D-RL	-0.27	0.10	-0.22	0.17	0.310		0.38
		ND-RL	0.10	0.15	0.06	0.22	0.310		0.46
	TO	D-TD	-0.46	0.17	-0.55	0.15	0.237		0.50
		ND-TD	0.41	0.30	0.45	0.25	0.735		0.27
		ND-RL	2.96	0.13	3.11	0.14	0.028	*	0.86
	TOΔ	1st half	0.87	0.38	1.00	0.26	0.091	†	0.57
		2nd half	2.55	0.35	2.66	0.26	0.176		0.50
		All	3.42	0.24	3.66	0.25	0.028	*	0.80

LS = last step; TO = takeoff; Δ = difference in values; D = dominant; ND = non-dominant; TD = touchdown; RL = release; Min = minimum; * = $p < .05$; † = $.05 \leqq p < .10$

The vertical displacement of CG decreases as the step number increases

The relative CG height of the 3-step trial was significantly larger at the dominant foot release of the last step compared to the 2-step trial. Significant trends ($p<.10$) were also observed at the minimum value of the last step, the minimum value of the takeoff, and the non-dominant foot touchdown of the takeoff. Additionally, the difference in relative CG height from the minimum to the non-dominant foot release of the takeoff of the 3-step trial was significantly smaller than that of the 2-step trial (Table 1). These findings suggest that the 3-step trial, with high horizontal velocity, maintained a higher CG position and minimized the vertical displacement of the CG from the last step to the takeoff. On the other hand, the trunk angle of the 3-step trial was significantly larger at the dominant foot touchdown, and a significant trend was observed at the non-dominant foot touchdown. The dominant ankle angle at non-dominant touchdown and the minimum showed a significant trend between 2 and 3-step trials (Table 2). These results demonstrated that raising the trunk upright and less dorsiflexion in the dominant ankle joint led to the reduced vertical displacement of CG in the 3-step trial. Wagner et al. (2009) previously reported that male volleyball athletes with larger jump heights exhibited smaller minimum CG heights and speculated that lowering minimum CG height could lead to increasing the distance to accelerate CG vertically until both feet release. However, in this study, despite an increase in jump height with more steps, the vertical CG displacement decreased. This result contradicts Wagner et al.'s (2009) findings. This implies that female volleyball athletes, having lower muscle strength than male volleyball athletes, were unable to lower their CG during the 3-step approach run with high horizontal velocity. Considering the above, coaches should avoid advising female volleyball athletes to lower their whole body during the 3-step spike jump.

Deceleration of horizontal velocity occurs in the first half of the takeoff as the step number increases

In the 3-step trial, horizontal velocity in the first half of the takeoff was significantly decelerated than the 2-step trial (Table 1). The heightened horizontal velocity resulting from an increased step number was decelerated by the dominant leg which is in contact with the ground during the first half of the takeoff. While the 2-step trial demonstrated marginal horizontal velocity deceleration of the first half (-0.03 m/s), the 3-step trial, with higher horizontal velocity, demonstrated a significant deceleration of horizontal velocity (-0.30 m/s). Chen et al. (2008) conducted a comparison of front row and back row attacks among female volleyball athletes. They found that the back row attack exhibited larger jump height and horizontal velocity after foot release. Conversely, the front row attack compromised on jump height to decelerate horizontal velocity, thereby averting the risk of the body making contact with the net in the flight phase. In this study, this deceleration of horizontal velocity in the front row attack was observed in only the 3-step trial with higher horizontal velocity. Fuchs et al. (2019b) also reported a negative correlation between horizontal velocity and CG angle, as well as a negative correlation between CG angle and horizontal negative force exerted by the dominant leg. This suggests that volleyball athletes with higher horizontal velocity during the approach run possess a smaller CG angle and decelerate their horizontal velocity using their dominant leg. In this study, the dominant thigh angle at the dominant foot touchdown and the difference in the dominant knee angle from the dominant foot touchdown to the minimum value were significantly larger in the 3-step trial with higher horizontal velocity. Significant trends were also identified in the CG angle and the dominant shank angle at the dominant foot touchdown (Table 2). This implies that by maintaining the thigh and shank closer to horizontal alignment and increasing flexion in the dominant knee joint, the enhanced horizontal velocity resulting from the increased step number was effectively reduced.

The non-dominant leg joints rapidly extend in the second half of the takeoff as the step number increases

In the second half of the takeoff, the maximum non-dominant hip and ankle angular velocities showed significant differences between 2 and 3-step trials. Additionally, a significant trend was identified in the non-dominant knee angular velocity at the non-dominant foot release (Table 3). Consequently, in the 3-step trial, the non-dominant hip, knee, and ankle joints underwent swift extension, leading to an increase in vertical velocity at non-dominant foot release. Additionally, horizontal velocity in the 3-step trial was also significantly higher even at the non-dominant foot touchdown (Table 1). These results imply that participants took advantage of the higher horizontal velocity of the 3-step trial to rapidly stretch the extensor muscle groups of lower limb joints in the second half of the takeoff, thereby storing more elastic energy and swiftly extending

Table 2. Comparison of joint and segment angles.

Variable			2 step		3 step		Wilcoxon signed-rank		
			M	SD	M	SD	p		ES (r)
D-Hip	TO	D-TD	110.0	7.0	111.1	5.2	0.310		0.35
		ND-TD	121.4	11.9	123.4	11.2	0.735		0.28
		D-RL	187.9	5.6	193.2	11.9	0.128		0.43
ND-Hip	TO	ND-TD	104.6	11.1	106.9	10.2	0.128		0.48
		ND-RL	181.1	7.0	180.9	5.2	1.000		0.03
D-Knee	TO	D-TD	138.3	6.6	140.7	6.8	0.237		0.44
		Min	98.0	5.5	96.4	6.4	0.237		0.47
		ND-TD	98.8	5.5	97.1	5.8	0.310		0.48
		D-RL	160.1	7.3	157.8	8.5	0.735		0.20
	TOΔ	D-TD - Min	40.3	9.8	44.3	9.6	0.018	*	0.77
		Min - D-RL	62.1	10.3	61.4	11.1	0.612		0.06
ND-Knee	TO	ND-TD	145.2	8.1	148.9	8.5	0.128		0.63
		Min	133.9	6.2	135.0	9.0	1.000		0.11
		ND-RL	173.7	2.6	175.1	2.9	0.237		0.43
	TOΔ	ND-TD - Min	11.2	6.1	13.9	7.6	0.310		0.37
		Min - ND-RL	39.8	7.4	40.1	9.6	0.735		0.03
D-Ankle	TO	D-TD	67.9	3.6	67.4	5.5	0.866		0.14
		ND-TD	54.8	1.9	58.7	6.7	0.091	†	0.63
		Min	54.1	2.5	57.7	6.8	0.091	†	0.61
		D-RL	116.1	3.3	117.0	5.8	0.735		0.14
	TOΔ	D-TD - Min	13.8	4.9	9.7	8.0	0.043	*	0.73
		Min - D-RL	62.1	4.6	59.2	5.9	0.310		0.42
ND-Ankle	TO	ND-TD	100.8	12.0	101.3	16.7	0.398		0.05
		Min	84.2	8.8	82.5	13.1	0.499		0.12
		ND-RL	129.5	2.1	130.3	4.2	0.866		0.21
	TOΔ	ND-TD - Min	16.6	10.0	18.8	12.7	0.398		0.29
		Min - ND-RL	45.3	8.4	47.8	11.2	0.310		0.27
Trunk	TO	D-TD	69.9	4.5	73.4	4.1	0.018	*	0.90
		ND-TD	67.1	4.8	69.8	5.7	0.063	†	0.74
		ND-RL	93.4	2.2	94.6	3.7	0.176		0.45
CG	TO	D-TD	59.6	3.8	56.2	4.1	0.063	†	0.75
		ND-RL	112.9	4.4	113.6	5.4	0.499		0.15
D-Thigh	TO	D-TD	48.7	3.4	51.2	2.5	0.018	*	0.82
		ND-TD	31.7	10.2	32.4	7.2	0.866		0.12
		D-RL	-21.9	4.1	-19.9	4.5	0.310		0.46
ND-Thigh	TO	ND-TD	51.6	6.7	50.9	5.9	0.398		0.33
		D-RL	6.6	2.4	7.9	4.8	0.499		0.31
D-Shank	TO	D-TD	11.0	6.5	16.5	7.3	0.063	†	0.69
		ND-TD	-44.5	6.4	-44.7	8.7	0.612		0.03
		D-RL	-31.9	4.7	-34.8	6.0	0.176		0.45
ND-Shank	TO	ND-TD	26.7	6.9	31.4	8.6	0.018	*	0.90
		D-RL	3.9	2.6	4.7	4.3	0.499		0.29

TO = takeoff; Δ = difference in values; D = dominant; ND = non-dominant;
TD = touchdown; RL = release; Min = minimum; * = $p < .05$; † = $.05 \leqq p < .10$

the hip, knee, and ankle joints. Wagner et al. (2009) speculated that the dominant leg contributed predominantly to a vertical acceleration of the CG, whereas the non-dominant leg served to stabilize the movement in the horizontal direction and assist in translation of acceleration from horizontal into the vertical direction. Fuchs et al. (2019b) emphasized the importance of the dominant leg in enhancing jump height since the maximum dominant knee angular velocity exhibited a stronger correlation coefficient with jump height compared to that of the non-dominant knee. Previous research thus underscored the importance of the dominant leg in achieving higher jump height. However, this study indicated that the contribution of the non-dominant leg to attaining vertical velocity becomes more pronounced at higher horizontal velocity.

Table 3. Comparison of joint angular velocities.

Variable			2 step		3 step		Wilcoxon signed-rank		
			M	SD	M	SD	p		ES (r)
D-Hip	TO	D-TD	34.3	54.9	25.6	25.3	0.612		0.16
		Min	-148.0	66.3	-167.9	74.7	0.398		0.37
		ND-TD	357.6	56.7	374.3	63.1	0.866		0.25
		Max	654.1	170.9	636.0	135.5	0.735		0.14
		D-RL	471.0	252.0	478.4	134.2	0.735		0.03
ND-Hip	TO	ND-TD	343.7	108.8	320.3	88.0	0.237		0.57
		Max	641.8	112.4	709.9	94.2	0.028	*	0.80
		ND-RL	520.4	58.2	531.0	173.2	0.499		0.06
D-Knee	TO	D-TD	-58.4	67.3	-81.3	81.4	0.499		0.25
		Min	-313.7	66.9	-400.3	142.9	0.018	*	0.65
		ND-TD	-16.7	80.8	-37.4	84.6	0.398		0.48
		Max	852.1	119.3	814.4	128.3	0.176		0.29
		D-RL	388.9	244.1	472.5	146.7	0.735		0.30
ND-Knee	TO	ND-TD	88.2	150.3	65.2	94.3	0.612		0.23
		Min	-253.3	84.4	-284.1	115.0	0.499		0.29
		Max	641.7	102.9	685.5	88.1	0.310		0.33
		ND-RL	165.5	144.7	262.5	115.5	0.063	†	0.74
D-Ankle	TO	D-TD	153.8	104.0	147.0	52.3	0.735		0.09
		Min	-227.2	48.4	-253.4	51.6	0.176		0.54
		ND-TD	-11.9	80.0	3.8	72.6	1.000		0.19
		Max	844.2	93.3	812.5	137.5	0.866		0.25
		D-RL	496.2	102.1	446.9	163.4	0.735		0.29
ND-Ankle	TO	ND-TD	34.2	272.0	32.8	380.6	1.000		0.01
		Min	-407.8	144.0	-473.9	164.8	0.128		0.56
		Max	668.4	79.7	761.6	114.2	0.043	*	0.78
		ND-RL	460.4	143.2	514.5	238.5	0.499		0.32

TO = takeoff; Δ = difference in values; D = dominant; ND = non-dominant;
TD = touchdown; RL = release; Min = minimum; Max = Maximum;
* = $p < .05$; † = $.05 \leqq p < .10$

SUMMARY

This study clarified the impact of varying step numbers within the approach run on jumping kinematics. Seven female volleyball athletes were tasked with executing spike jumps, employing 2 and 3-step approach runs. Increasing the step number enhances the horizontal velocity and jump height. Regarding jumping kinematics, as the step number increases, the vertical displacement of CG decreases. Additionally, deceleration of horizontal velocity occurs in the first half of the takeoff and the non-dominant leg joints rapidly extend in the second half of the takeoff.

REFERENCES

1. Ae, M (1996). Body segment inertia parameters for Japanese children and athletes. Jpn. J. Sports Sci., 15, 155-162.

2. Chen, P C, Huang, C F, and Shih, S M (2011). Differences in 3D kinematics between genders during volleyball spike. Proceedings of the Congress of the International Society of Biomechanics.

3. Fuchs, P X, Fusco, A, Bell, J W, Duvillard, S P, Cortis, C, and Wagner, H (2019a). Movement characteristics of volleyball spike jump performance in females. J. Sci. Med. Sport, 22, 833–837. doi: 10.1016/j.jsams.2019.01.002

4. Fuchs, P X, Menzel, H J, Guidotti, F, Bell, J, Duvillard, S P, and Wagner, H (2019b). Spike jump biomechanics in male versus female elite volleyball players. J. Sports Sci., 37, 2411–2419. doi: 10.1080/02640414.2019.1639437

5. Hsieh, C, and Christiansen, C L (2010). The effect of approach on spike jump height for female volleyball players. Int. J. Sports Sci. Coaching, 5(3), 373–380. doi: 10.1260/1747-9541.5.3.373

6. Ikeda, Y, Sasaki, Y, and Hamano, R (2018). Factors influencing spike jump height in female college volleyball players. J. Strength. Cond. Res., 32(1), 267-273. doi: 10.1519/JSC.0000000000002191

7. Khayambashi, K (1986). Effects of approaches and take-offs on the vertical jump in volleyball. Snipes J., 9(1), 1-7.

8. Navalta, J W, Stone W J, and Lyons, T S (2019). Ethical Issues Relating to Scientific Discovery in Exercise Science. Int. J. Exerc. Sci., 12(1), 1-8.

9. Wagner, H, Tilp, M, Duvillard, S P, and Müller, E (2009). Kinematic analysis of volleyball spike jump. Int. J. Sports Med., 30, 760–765. doi: 10.1055/s-0029-1224177