BIOMECHANICAL STUDY ON DIFFERENT DIRECTIONS FOR RUNNING JUMPS FOCUSED ON THE TAKEOFF PREPARATION

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This study aimed to elucidate the difference in CG parameters from three steps, prejump to takeoff step of the jump motion (running jump), and obtain primary data on takeoff preparation action. Five male jumpers associated with the university track and field department were trained to perform their best at (1) approach run with no takeoff (RUN), (2) jumping as far as possible (long jump [LJ]), and (3) jumping as high as possible (high jump [HJ]), which were recorded using a three-dimensional capture system. As a result, significant differences were observed in not only the takeoff but also the takeoff preparation phase regarding CG parameters, suggesting the need to focus on the takeoff preparation phase as a factor that determines jump direction. Moreover, HJ and LJ suppressed an increase in vertical velocity one step prior, and by takeoff at a lower CG, the athletes allowed for an easier increase in takeoff angle and jump height. However, to resist a decrease in horizontal velocity, LJ transitioned to takeoff in a manner closer to RUN and without changing takeoff preparation as much as that in HJ. Thus, adjusting vertical velocity and height one step before takeoff can influence takeoff angle.

KEYWORDS: running jump, takeoff preparation, long jump, high jump.

INTRODUCTION: Jumping with approach running (running jumps), such as in long jumps and basketball running shots, has been observed and analyzed in a number of sports (Hay, 1978; Suzuki et al., 2016). Running jumps mainly consists of five phases, which are approach run, takeoff preparation, takeoff, air, and landing. and considerable research has been conducted on takeoff, which is considered particularly important. Additionally, most studies on running jumps have focused on jumping higher or farther, typically for track and field jumps (Ae et al., 1999; Fischer, 2014). However, in many other sports, not only are jump height and distance required, but launching the body at a determined height and distance, that is, to jump in different directions, is also important. The direction of the jump is determined by the takeoff; however, to achieve an effective takeoff in a short time, it is necessary to focus on the preceding takeoff preparation. Therefore, this study aimed to clarify the difference in center of gravity (CG) parameters from three steps before takeoff during the jump action (running jump) with approach runs for different jump directions. In addition, basic primary data on the takeoff preparation action were obtained.

METHODS: Five male jumping athletes (height, 1.74 ± 0.07 m; weight, 65.4 ± 4.0 kg) associated with the university track and field department were included in this study. At the beginning of the experiment, all subjects were fully informed of the objectives, methods, and risks associated with the study, and consent to participate in the study was obtained.
The following three skills were performed with utmost effort on the part of the athletes: (1) approach run without takeoff (RUN), (2) jumping as far as possible (long Jump [LJ]), and (3) jumping as high as possible (high jump [HJ]). Approach runs involved pulling a line parallel to the jump direction on the ground, and athletes were instructed to follow the line. The number of approach run steps was set to five, and any approach run distance was allowed (7.7 ± 0.4 m) depending on the athlete. The athletes were allowed to perform sufficient preparatory exercises before the experimental procedure and practice the experimental procedure to become comfortable with the approach run distance and foot positions.
In data collection, a three-dimensional capture system (Vicon Motion Systems, 250 Hz) was used to obtain coordinate data for each part of the body (41 points) from three steps before the jump to the takeoff in each test. The Global coordinate system was defined as a right-hand coordinate system with the Y-axis in the direction of forward movement, and the X-axis in the

left/right direction, and the Z-axis in the vertical direction. The resulting coordinate data was smoothed using a Butterworth low-pass digital filter. The optimal cutoff frequency was determined using the method described by Yu et al. (1999). In this study, the body's CG was determined using the Ae (1996) method.

The calculated items included the longest (maximum CG distance) and highest (maximum CG height) points achieved (calculated from the CG velocity when taking off from the ground), horizontal velocity, vertical velocity, takeoff angle, and CG height.

The phases from approach run to takeoff are presented in Figure 1. L3, L2, and L1 refer to three, two, and one steps before takeoff, respectively; on and off refer to contact with the ground. TD is contact with the ground before takeoff, and TO is takeoff from the ground.

Values for each item were presented as mean ± SD for each phase. For comparison of CG parameters between experiment attempts (RUN, LJ, and HJ), one-way repeated measures ANOVA and Bonferroni's post hoc test were performed. The significance level was set at $p < 0.05$.

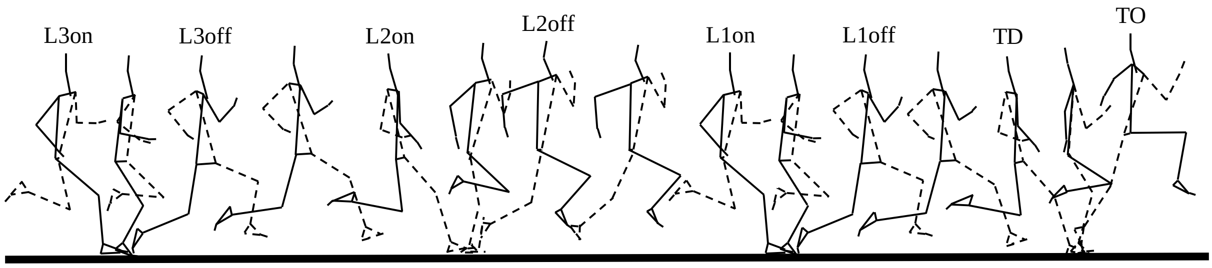

Fig.1 Definition of each phase

RESULTS: Table 1 lists maximum CG distance and maximum CG distance achieved for each phase. Major differences were observed between tests for longest point achieved, with LJ superior to both RUN and HJ. The longest points achieved for each test were 3.45 ± 0.26 m for RUN, 4.45 ± 0.26 m for LJ, and 3.68 ± 0.41 m for HJ. The highest points achieved were significantly different for all tests, in increasing order of RUN, LJ, and HJ. The highest points achieved in each test were 1.05 ± 0.09 m for RUN, 1.53 ± 0.11 m for LJ, and 1.77 ± 0.06 m for HJ.

Table 1 . Comparison of CG parameters between trials in each phase

Maximum CG Distance (m)	RUN	3.45	±	0.26
	LJ	4.45	±	0.26
	HJ	3.68	±	0.41
Maximum CG Height (m)	RUN	1.05	±	0.09
	LJ	1.53	±	0.11
	HJ	1.77	±	0.06

Table 2 shows horizontal and vertical velocity, takeoff angle, and CG height in each phase. The main effect was observed on horizontal velocity between tests when TO, in decreasing order of RUN, LJ, and HJ. The main effect on vertical velocity between tests was observed when L2on, L1off, TD, and TO. The values for LJ were smaller than that of HJ when L2on. When L1off, values decreased in the order of RUN, LJ, and HJ. The values for RUN were smaller than those of LJ and HJ when TD and TO. The main effect on takeoff angle between tests was observed when L1off and TO. When L1off, values decreased in the order of RUN, LJ, and HJ. RUN during TO was significantly smaller than LJ and RUN. The main effect on CG height between tests was observed when L1off, TD, and TO. The values for HJ was smaller compared with RUN and LJ when L1off. RUN, LJ, and HJ sequentially decreased during TD. RUN, LJ, and HJ are sequentially increased during TO.

Table 2 . Comparison of CG parameters between trials in each phase

		L3on	L3off	L2on	L2off	L1on	L1off	TD	TO
Horizontal Velocity (m/s)	RUN	4.26 ± 0.19	5.04 ± 0.28	5.07 ± 0.17	5.60 ± 0.25	5.63 ± 0.22	6.08 ± 0.30	5.98 ± 0.25	6.14 ± 0.34
	LJ	4.37 ± 0.15	5.16 ± 0.19	5.15 ± 0.17	5.74 ± 0.21	5.72 ± 0.20	6.10 ± 0.23	6.04 ± 0.23	5.36 ± 0.35
	HJ	4.31 ± 0.08	5.11 ± 0.12	5.07 ± 0.09	5.62 ± 0.11	5.59 ± 0.10	5.79 ± 0.16	5.73 ± 0.19	3.94 ± 0.53
Sig. diff.									RUN > LJ
									RUN > HJ
									LJ > HJ
Vertical Velocity (m/s)	RUN	-0.69 ± 0.15	0.61 ± 0.11	-0.64 ± 0.19	0.49 ± 0.16	-0.63 ± 0.13	0.68 ± 0.07	-0.64 ± 0.12	0.99 ± 0.23
	LJ	-0.71 ± 0.07	0.66 ± 0.09	-0.73 ± 0.08	0.49 ± 0.09	-0.63 ± 0.15	0.34 ± 0.12	-0.39 ± 0.13	2.69 ± 0.19
	HJ	-0.65 ± 0.12	0.57 ± 0.12	-0.51 ± 0.04	0.43 ± 0.13	-0.69 ± 0.14	-0.04 ± 0.13	-0.35 ± 0.12	3.29 ± 0.28
Sig. diff.							RUN > LJ	RUN < LJ	RUN < LJ
							RUN > HJ	RUN < HJ	RUN < HJ
				LJ < HJ			LJ > HJ		
Takeoff Angles (deg)	RUN		6.86 ± 1.30		4.99 ± 1.73		6.43 ± 0.71		9.21 ± 2.14
	LJ		7.27 ± 1.13		4.93 ± 0.95		3.24 ± 1.14		26.75 ± 2.78
	HJ		6.36 ± 1.25		4.35 ± 1.31		-0.44 ± 1.31		40.09 ± 5.81
Sig. diff.							RUN > LJ		RUN < LJ
							RUN > HJ		RUN < HJ
							LJ > HJ		
CG Height (m)	RUN	0.93 ± 0.05	0.94 ± 0.05	0.94 ± 0.05	0.95 ± 0.05	0.95 ± 0.05	0.96 ± 0.04	0.96 ± 0.05	1.00 ± 0.07
	LJ	0.92 ± 0.05	0.95 ± 0.05	0.94 ± 0.05	0.95 ± 0.04	0.93 ± 0.05	0.93 ± 0.05	0.93 ± 0.06	1.16 ± 0.07
	HJ	0.97 ± 0.04	0.96 ± 0.04	0.96 ± 0.04	0.94 ± 0.05	0.92 ± 0.05	0.89 ± 0.06	0.88 ± 0.07	1.22 ± 0.06
Sig. diff.								RUN > LJ	RUN < LJ
							RUN > HJ	RUN > HJ	RUN < HJ
							LJ > HJ	LJ > HJ	LJ < HJ

Values are expressed as mean ± SD
One-way repeated measures ANOVA is used for statistical analysis. > or < : P < 0.05

DISCUSSION: Several studies on jumping mechanics (running jumps) employing assist techniques have focused on approach run or takeoff phases, but few have focused on the takeoff preparation phase. Therefore, CG parameters at the time of takeoff preparation, which links approach run with takeoff, were calculated, followed by an investigative comparison considering jump direction. LJ was farthest and HJ was highest with respect to longest and highest points achieved, as described in this study. HJ was higher by reducing the increase in vertical velocity on prestep and transitioning to the takeoff at a low CG, making it easier to increase takeoff angle. In LJ, an easier takeoff angle increase was achieved in the same manner as HJ; therefore, LJ was farther. However, because, in LJ, vertical velocity needs to increase while avoiding a loss of horizontal velocity (Hay, 1993; Ae et al., 1999), neither vertical velocity nor CG position changed significantly, and there was no takeoff preparation as in HJ. There was a takeoff preparation executed in a manner similar to RUN.

CONCLUSION: Significant differences were observed in not only the takeoff phase but also in the takeoff preparation phase of the CG parameters in three different trajectory tests (RUN, LJ, and HJ). Thus, it was suggested that the takeoff preparation phase affects the direction of the jump. HJ was higher when the increase in vertical velocity on prestep was reduced and by transitioning to the takeoff at a low CG, making it easier to increase takeoff angle. Additionally, while the decrease in horizontal velocity was restricted in LJ, the takeoff angle was increased similar to that in HJ, and the jump was farther. Therefore, adjusting vertical velocity and CG height one step before takeoff can influence takeoff angle.

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