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Influence of Takeoff and Landing Displacement Strategies on Standing Long Jump Performance

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ABSTRACT

We evaluated the influence of takeoff and landing distance contributions to measured jump distance during the standing long jump (SLJ). Twenty male soccer players performed three SLJs while ground reaction force data (GRF) were obtained. The horizontal distances created by lower body position (D_{BODY}) prior to takeoff (D_{TO}) and landing (DLA) were calculated. Ratios for D_{TO} (R_{TO}) and D_{LA} (R_{LA}) were calculated relative to standing height, quantifying the proportion of measured jump distance (D_{JUMP}) created during each phase. Variables were compared using dependent t-tests (α=0.05) and effect sizes (ES; large>1.2). Pearson correlations determined the relationships among variables. R_{LA} was greater than R_{TO} (p<0.001). D_{LA} was greater than D_{TO} (p<0.001). Very large ES were detected between R_{TO} and R_{LA} and D_{TO} and D_{LA} (ES≥2.53). Near perfect correlations were identified between D_{TO} and R_{TO} (r=0.96; p<0.001) and D_{LA} and R_{LA} (r=0.99; p<0.001). Strong correlations were identified between D_{JUMP} and R_{LA} (r=0.63; p=0.003) and D_{BODY} and DJUMP (r=0.70; p<0.001). It is concluded that D_{LA} more greatly influences the total distance measured during the SLJ versus D_{TO}. These results highlight athletes' strategy to maximize jump distance (flight distance plus the distances prior to takeoff and landing) during SLJ tests.

Keywords: Biomechanics; Force Platform; Performance; Soccer; Standing Long Jump.

INTRODUCTION

Physical performance tests are used to evaluate athletic potential or the current level of performance[1] in high-level athletes. Both vertical and horizontal jumps[2-7] are common examples, as each task is related to sprinting, jumping, and agility movements involving a combination of vertical and horizontal force production.[8,9] Further, horizontal jumps (i.e., standing long jumps; SLJ) have been shown to be better predictors of sprinting and change of direction ability than vertical jumps.[8-10] When evaluating SLJs, jump distance (measured at the foot) is the primary performance metric[4,6] while ground reaction force (GRF) and temporal parameters[4,10] are often assessed to explain the measured jump distance. However, changes in lower body position prior to both takeoff and landing can greatly alter jump distance.[11-13] For instance, when lower body segments are positioned further away from the center of mass before takeoff and/or landing, the measured distance can increase despite an unchanged magnitudes of horizontal center of mass flight displacement,[13,14] force application, rates of force development, or power productions.[15]

Although the distances created prior to takeoff and landing can alter the measured distance, no study to date has directly examined the effects of these distances during a horizontal jump test. Such examination can both reveal the value of creating horizontal distance prior to takeoff or landing and provide a methodology to further explore athletes' SLJ strategies. It is possible that an investigation of this type has yet to be performed because the horizontal distances created by lower body position prior to takeoff and landing are thought to be difficult to quantify without three-dimensional motion capture systems with substantial capture volumes. Such systems might not be available to many strength and conditioning professionals due to the space requirements to properly track total body and segmental motion during jumping, the high cost (> $100,000) associated with motion capture systems, or both. Still, force platforms have been used for many years in human performance settings[16] and their use continues to grow in popularity among strength and conditioning professionals seeking to evaluate jump and other physical performance qualities.[17] Importantly, GRF data obtained via force platforms are the sum of the forces acting at the center of mass.[18] Thus, all center of mass kinematics calculated from GRF data can be used to evaluate changes without needing to be validated against motion capture systems.

Strength and conditioning professionals could benefit from a force platform methodology to compare the distances created by lower body position prior to takeoff (D_{TO}) and landing (D_{LA}) during maximum effort SLJs to supplement assessments of jumping strategies. Therefore, the purpose of this investigation was to present such a method and compare the D_{TO} and D_{LA} distances in addition to ratios of both D_{TO} and D_{LA} to the standing height of the participant (R_{TO} and R_{LA}, respectively). The ratios served as relative values that can be evaluated over time and between/among individuals. Additionally, we aimed to evaluate R_{TO} and R_{LA} to determine which ratio was more strongly correlated with measured horizontal jump distance. It was hypothesized that D_{LA} and R_{LA} would be greater than D_{TO} and R_{TO}. We also hypothesized that R_{LA} would be more strongly correlated to jump distance than R_{TO}.

METHODS

A convenience sample of twenty NCAA Division 1 male soccer players (19.4 ± 1.4 y; 179.9 ± 8.2 cm; 82.1 ± 18.9 kg) volunteered to participate in this study. All participants were free of any injury that would limit their ability to perform maximum effort standing long jumps. All participants were active members of the university's soccer team at the time of testing. Prior to any experimental measurements, participants were informed of the study purpose. Then, written informed consent was provided to the investigators as approved by the Institutional Review Board at the site of data collection in accordance with the Declaration of Helsinki.

Participants completed one laboratory session. Height and mass were recorded, and the participants provided their age. The participants completed a self-selected warm-up (≤ 10 min) consisting of a combination of static and dynamic stretching, followed by approximately five submaximal vertical and horizontal jumps. After the warm-up, participants performed up to five practice attempts to familiarize themselves with the laboratory environment and the SLJ task. Participants then performed three maximum effort trials on a dual force platform system (Kistler Instruments, Corp., Amherst, NY; 1000 Hz) interfaced to a PC running Bioware® (version 4.0.1.2). Trials began with the participants standing still with each foot positioned on a force platform for ~2 seconds. Upon a "go" command, participants jumped forward as far as possible using a self-selected countermovement depth and arm swing. Upon landing, participants were instructed to return to a motionless standing position. Trials were discarded and repeated if a participant was unable to land and return to a motionless standing position or an attempt was considered to be of sub-maximal effort by the participant, researchers, or both. No participant required more than nine attempts to successfully complete three recorded trials. Jump distance was initially measured at the ground using marked tape adhered to the laboratory floor. An investigator visually monitored the point of heel contact at landing, and jump distance was initially measured as the distance between the edge of the force platforms and the location of the heels upon landing.[4] This jump distance was used during the data analysis processes described later.

Data were exported to MATLAB (R2015b; The Mathworks, Inc., Natick, MA). Raw GRF signals were smoothed using a fourth order, bi-directional, low pass Butterworth digital filter and a cutoff frequency of 50 Hz, with the filter order and cutoff frequency set before the bi-directional passes.[19] The smoothed GRF data from the two force platforms were summed to obtain total GRF profiles along the vertical and anterior-posterior axes. Vertical and horizontal acceleration profiles were then calculated from the GRF profiles using Newton's law of acceleration ($a = \Sigma F/m$) accounting for gravity as appropriate. Vertical and horizontal velocities were calculated as the cumulative time integrals of the respective acceleration profiles using the trapezoidal rule. The horizontal displacement of the center of mass was then calculated as the cumulative time integral of the horizontal velocity profile using the trapezoidal rule.

The anterior-posterior locations of each foot's center of pressure (relative to the center of the platforms) was subtracted from the center of pressure locations when standing still to obtain the distance of the toes to the edge of the platforms at takeoff. The shortest of these two distances was added to the measured distance at the ground to provide the true jump distance measured from the forefoot (D_{JUMP}). In turn, D_{JUMP} best replicated testing situations in which an athlete jumps with their forefoot positioned on a marked line.[4] The probability of different center of mass heights at takeoff versus landing was not a concern because our objective was to determine the total effect of body position prior to both takeoff and landing. As such, center of mass flight distance (D_{COM}) was calculated from the vertical and horizontal center of mass velocity data using equations of uniformly accelerated motion. Specifically, the vertical and horizontal center of mass velocities were extracted at takeoff, which was defined as the time when vertical GRF decreased below 20 N, which was determined according to the typical magnitude of GRF recorded when these force platforms are not loaded. Then, the total time in the air was calculated using the following equation[18] where V_Z represents the vertical velocity at takeoff, and 9.81 represents the absolute value of gravitational acceleration:

$$T = 2*(V_Z/9.81)$$

DCOM was then calculated using the following equation[18] where V_Y represents the horizontal velocity at takeoff and T represents the time in the air:

$$D_{COM} = V_Y * T$$

The added distance created by the positioning of the lower body prior to both takeoff and landing (D_{BODY}) was determined by subtracting D_{COM} from D_{JUMP}. The horizontal distance between the center of mass and the forefoot at takeoff (D_{TO}; Figure 1) was extracted from the horizontal displacement data to obtain the takeoff portion of D_{BODY} while accounting for the anterior-posterior center of pressure at takeoff and standing. As with the adjustment for D_{JUMP}, accounting for the center of pressure at takeoff allowed for the calculation of the horizontal center of mass distance from the forefoot. Finally, the distance created by lower body position prior to landing (D_{LA}; Figure 1) was calculated by subtracting D_{TO} from D_{BODY}. Then, D_{TO} and D_{LA} were divided by the standing height of the participant to calculate the relative metrics, R_{TO} and R_{LA}, respectively, for between-participant comparisons as needed.

Mean values were calculated across the three trials per participant for D_{JUMP}, D_{BODY}, D_{TO}, D_{LA}, R_{TO}, and R_{LA}, respectively. Paired samples t-tests were used to compare both R_{TO} and R_{LA} and D_{TO} and D_{LA} ($\alpha = 0.05$). To present the magnitudes of the mean differences, Cohen's *d* effect size (ES) values[20] were calculated and interpreted using Hopkins' [21]

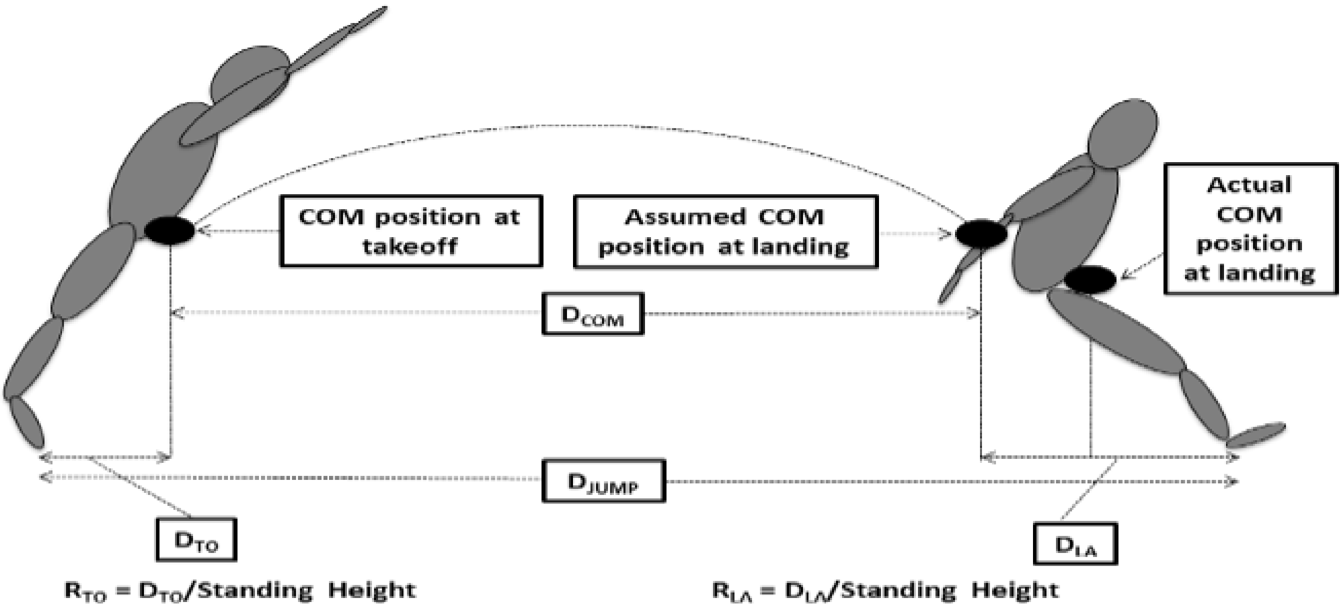

Figure 1. Theoretical Representation of the Measured Distance, Center of Mass Flight Distance, and the Takeoff and Landing Distances during the Standing Long Jump.
Notes - D_{COM}: Estimated center of mass flight distance via projectile motion; DJ_{UMP}: Measured jump distance at the foot; D_{TO}: Distance added to D_{COM} prior to takeoff; D_{LA}: Distance added to D_{COM} prior to landing; R_{TO}: Ratio of D_{TO} and standing height; R_{LA}: Ratio of D_{LA} and standing height.

scale (0.0 < trivial < 0.2 ≤ small < 0.6 ≤ moderate < 1.2 large < very large ≤ 2.0). Pearson product-moment correlation coefficients were presented to determine the relationships among D_{JUMP}, D_{BODY}, D_{TO}, D_{LA}, R_{TO}, and R_{LA}. The magnitudes of the correlations were interpreted using Hopkin's[21] scale (0 < trivial ≤ 0.1 < small ≤ 0.3 < moderate ≤ 0.5 < large ≤ 0.7 < very large 0.9). Data normality was assessed using the Shapiro-Wilk test, and linearity was inspected using scatterplots. The correlation coefficients were accompanied by 90% confidence intervals (CI).[22] The coefficient of variation (CoV) was calculated to document the consistency among participants for each variable of interest. In accordance with previous literature, performance among participants was considered consistent if the CoV was ≤ 10%.[23]

RESULTS

The average R_{LA} across participants was significantly greater than R_{TO} ($p < 0.001$; Table 1). The average D_{LA} was significantly greater than D_{TO} ($p < 0.001$; Table 1). Additionally, the magnitudes of the differences between R_{TO} and R_{LA} and D_{TO} and D_{LA} were very large (ES = 2.53, ES = 2.57, respectively), indicating the statistical differences were quite meaningful. The R_{TO}, R_{LA}, D_{BODY}, D_{TO}, D_{LA}, and D_{JUMP} values across participants are documented in Table 1. Significant, very large correlations were identified between D_{TO} and R_{TO} ($r = 0.96$; $p < 0.001$; 90% CI: 0.91 to 0.98; Figure 2), D_{LA} and R_{LA} ($r = 0.99$; $p < 0.001$; 90% CI: 0.98 to 1.00; Figure 2). Significant, large to very large correlations were identified between both D_{JUMP} and R_{LA} ($r = 0.63$; $p = 0.003$; 90% CI: 0.33 to 0.81; Figure 3), and D_{BODY} and D_{JUMP} ($r = 0.70$; $p < 0.001$; 90% CI: 0.44 to 0.85; Figure 3), respectively. A small, non-significant correlation was revealed between D_{JUMP} and R_{TO} ($r =-0.12$; $p = 0.628$; 90% CI: -0.48 to 0.27; Figure 3). Consistent performance (CoV = 9%) was detected across participants for D_{JUMP} (Table 1), while less consistent performance (CoV ≥ 17%) was detected for all other variables.

DISCUSSION

The purpose of this investigation was to compare D_{TO} and landing D_{LA} during maximum effort SLJs to a) determine whether it is more valuable to create horizontal distance prior to takeoff or prior to landing and b) provide a methodology to further explore athletes' SLJ strategies. This analysis revealed that R_{LA} was significantly greater than R_{TO}. As to be expected, the greater R_{LA} indicated that the D_{LA} was significantly greater than the D_{TO}. Additionally, the mean differences were very large in magnitude, indicating that the differences between R_{TO} and RLA and D_{LA} and D_{TO} were quite meaningful from a practical perspective.

The R_{TO} and R_{LA} values represent the proportion of an athlete's standing height positioned posterior and anterior to the center of mass positions at takeoff and landing, respectively. A larger R_{TO} indicates the athlete positioned their lower body such that the feet were further from the center of mass at takeoff to create greater horizontal distance at that instant. A larger R_{LA} indicates the athlete either extended their lower body such that the feet were further from the center of mass at the instant of landing or their hip and knee joints were flexed increase center of mass flight time and distance traveled. In this sample of high-level soccer athletes, greater jump distances were highly correlated with greater R_{LA} values, while greater R_{TO} values were negatively correlated with jump distances. This indicates that better horizontal jumpers may be more skilled at positioning the body prior to landing to augment the D_{JUMP} by increasing flight time. Conversely, the negative correlation between R_{TO} and D_{JUMP} indicates a reduction in performance is likely when the athlete creates too much distance between the COM and the feet prior to takeoff, possibly by excessive forward lean. The large magnitude CoV for R_{LA} and D_{LA} indicates that this sample of participants did not exhibit consistent lower body positional strategies prior to landing. It is likely some participants employed distinct preparatory strategies prior to landing [24], perhaps from greater positional awareness, which allowed them to produce greater D_{JUMP}. Such strategies could be examined in detail when using more common approaches to identify higher-skilled athletes from lesser-skilled athletes.[25,26]

Strength and conditioning professionals may be especially interested in their athletes' D_{TO}, D_{LA}, R_{TO} and R_{LA} displays, particularly during analyses that do not reveal differences in driver (force application, rate of force development) or strategy (jump phase durations, countermovement depth, etc.) variables typically focused on when seeking to explain an increase of decrease in flight time or jump distance. It is our opinion that coaches and strength and conditioning professionals can monitor an athlete's body awareness and/or control using R_{TO} and R_{LA}. By evaluating these parameters over time, chronic performance adaptations can be distinguished following training regimens aimed to

Table 1. Horizontal Distances and Ratios during the Standing Long Jump.

Participant	DJUMP (m)	DBODY (m)	DTO (m)	DLA (m)	RTO	RLA
1	2.24	1.03	0.35	0.68	0.20	0.38
2	2.15	1.12	0.35	0.77	0.19	0.43
3	2.28	1.13	0.38	0.75	0.21	0.42
4	2.52	1.20	0.35	0.85	0.18	0.43
5	1.97	0.63	0.47	0.16	0.28	0.10
6	1.83	0.79	0.33	0.47	0.19	0.27
7	2.19	1.14	0.26	0.88	0.15	0.50
8	2.25	1.47	0.45	1.02	0.25	0.57
9	2.02	0.90	0.25	0.65	0.14	0.36
10	2.25	0.91	0.36	0.55	0.21	0.32
11	2.38	1.10	0.38	0.72	0.20	0.38
12	1.90	0.71	0.27	0.44	0.16	0.27
13	2.37	1.09	0.31	0.78	0.16	0.41
14	2.09	1.12	0.30	0.82	0.16	0.44
15	2.15	0.95	0.35	0.60	0.18	0.32
16	2.60	1.20	0.31	0.89	0.17	0.50
17	2.49	1.24	0.29	0.95	0.16	0.51
18	2.18	1.01	0.30	0.71	0.18	0.42
19	2.14	0.89	0.32	0.57	0.18	0.32
20	2.23	1.15	0.29	0.86	0.16	0.48
Mean	2.21	1.04	0.33	0.71*	0.19	0.39**
SD	0.20	0.20	0.06	0.20	0.03	0.11
CoV	9%	19%	17%	28%	18%	28%

*Notes – D_{JUMP}: Measured jump distance at the foot; D_{TO}: Distance added to D_{COM} prior to takeoff; D_{LA}: Distance added to D_{COM} prior to landing; R_{TO}: Ratio of D_{TO} and standing height; R_{LA}: Ratio of D_{LA} and standing height; Mean: average value across participants; SD: ± one standard deviation; CoV: coefficient of variation; *: significantly greater than D_{TO} ($p < 0.05$); **: significantly greater than R_{TO} ($p < 0.05$).*

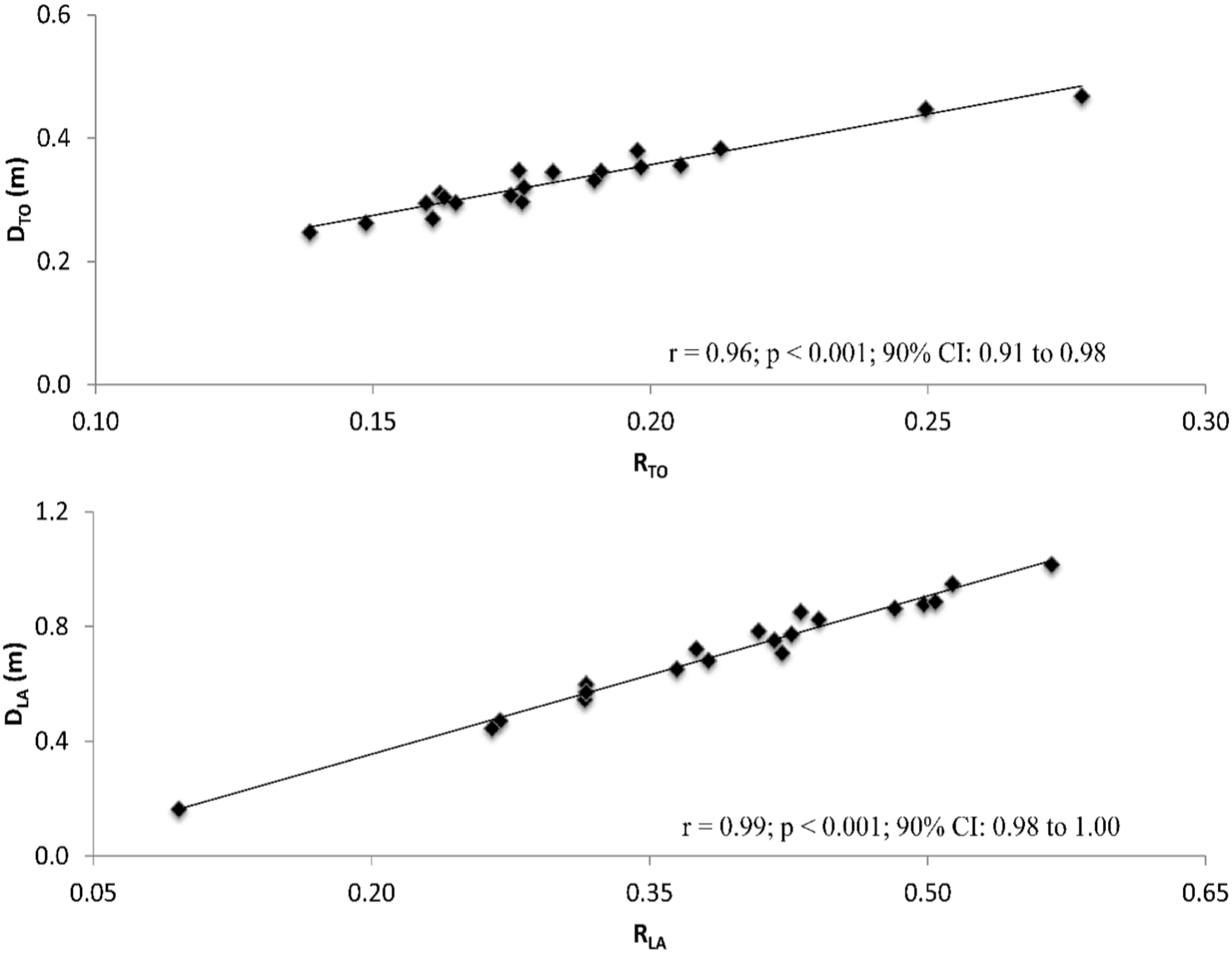

Figure 2. Correlations between Horizontal Distances and the Ratios for Standing Height at both for Takeoff and Landing.
Notes – Top graph: correlation between the added distance prior to takeoff (D_{TO}) and the ratio for height at takeoff (R_{TO}); Bottom graph: correlation between the added distance prior to landing (D_{LA}) and the ratio for height at landing (R_{LA}).

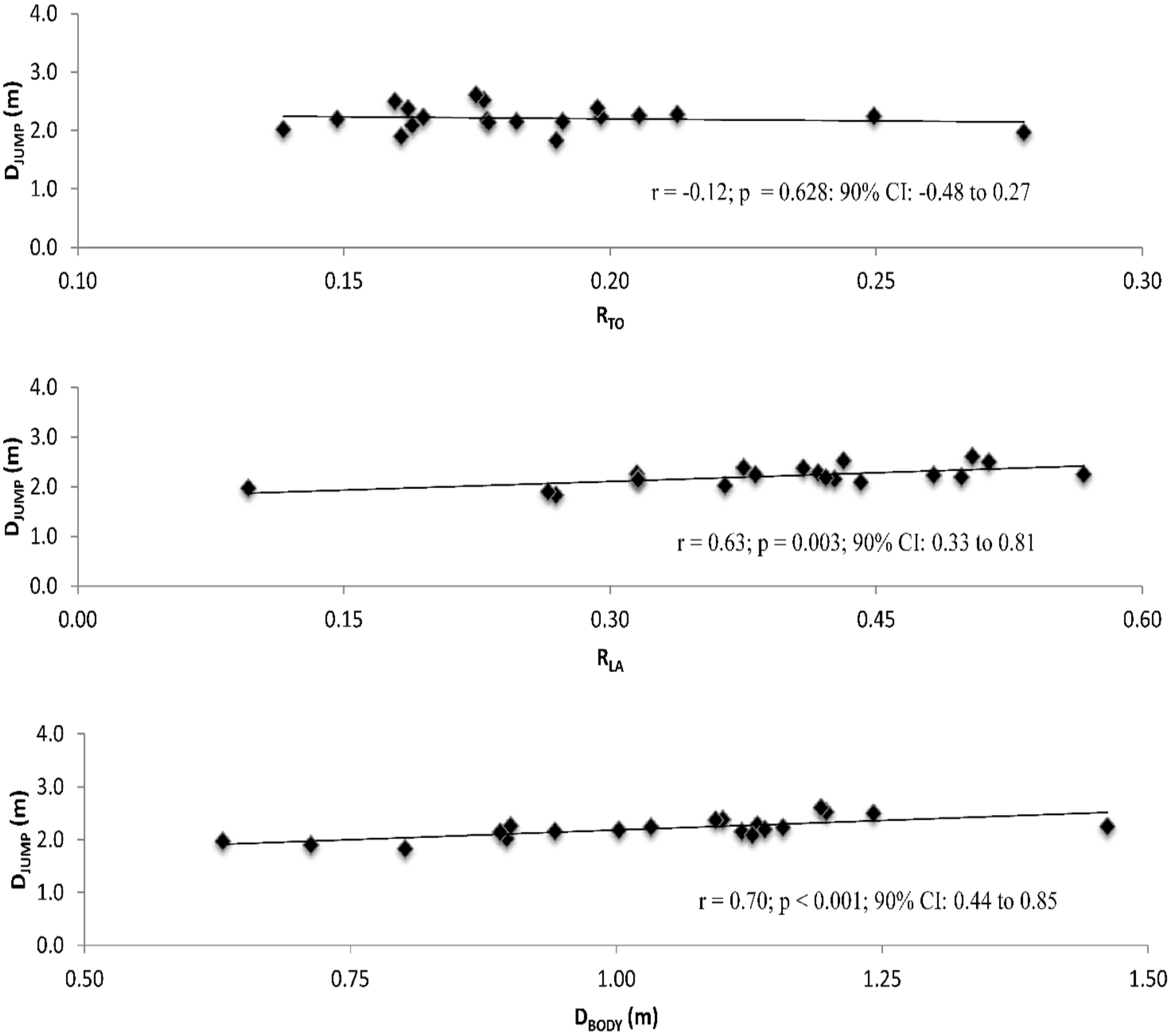

Figure 3. Correlations between Measured Horizontal Distances and the Added Horizontal Distances from Body Position.

Notes - Top Graph: correlation between the measured distance at the ground (D_{JUMP}) and the ratio of D_{TO} height (R_{TO}); Middle graph: correlation between D_{JUMP} and the ratio of D_{LA} and height (R_{LA}); Bottom graph: correlation between D_{JUMP} and the total added distance from body position at takeoff and landing (D_{BODY}).

improve body position prior to takeoff and landing. In addition, rehabilitation protocols that include jump tests could incorporate these parameters during return-to-play assessments. Speculatively, notably shortened D_{LA} and R_{LA} values could reflect protective mechanisms and a lack of preparedness for a return to competition. Relative to improving an athlete's display during physical performance tests, the current data indicate athletes should attain enhanced SLJ performance by manipulating body position prior to landing. Coaching cues related to this type of strategy could be obtained from track & field, as long jumpers and triple jumpers employ landing strategies that include increasing the D_{LA} component of their respective jumps[27]. This could be useful during test preparations with relatively short timeframes to stimulate and realize adaptations through physical training. Strength and conditioning professionals and athletes alike should incorporate this methodology and results when assessing an athlete's SLJ technique and performance.

A possible limitation of this study was the assumption that the vertical position of the center of mass was identical at takeoff and landing to perform the calculations described, as the vertical center of mass distances at takeoff and landing have been shown to differ substantially in favor of D_{TO}.[13] However, the greater D_{LA} (Table 1) observed in the current study represents the total effect of body position at that instant in time. This total effect of body position refers to an increased flight time, and thus, an increased distance travelled relative to the estimated center of mass flight time and distance travelled. This combined effect may reveal important information relative to body position training when targeting improved SLJ performance. However, directed efforts to increase DLA may need to emphasize that flexion actions executed during the flight phase be determined and completed during the latter portion of flight. This is because athletes' focus prior to the flight phase should likely be specific to the necessary forces to be applied into the ground to maximize D_{COM}. It would be disadvantageous to increase D_{LA} following a compromised D_{COM}, which would return an unchanged or even decreased D_{JUMP}. Lastly, the training levels and skill-sets of these participants could limit the generalizability of these results to other athletic/recreational populations. More comprehensive information could be gathered by examining different athletic populations with varying degrees of familiarity with the SLJ.

CONCLUSIONS

This study presented a method to obtain ratios that describe the proportions of standing height used to create additional horizontal distance during the takeoff and landing phases of the SLJ. This analysis was determined that R_{TO} was of smaller magnitude and was not as strongly associated with measured jump distance than R_{LA}. The proposed methodology could help strength and conditioning professionals examine their athletes' abilities to manipulate lower body position prior to landing such that flight time and jump distance increase without the need for motion capture technologies. Although athletes should emphasize force production capabilities, body awareness, and body positioning when participating in holistic training for improved SLJ performance, increasing D_{LA} and R_{LA} could be initial targets when preparing for physical performance (e.g., combine) tests.

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CONFLICT OF INTEREST STATEMENT

No potential conflict of interest was reported by the authors.

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