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Original Article

Phase ratios of American collegiate triple jumpers

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Abstract:
Published research on triple jumping technique is largely based on elite jumpers, potentially limiting its application to less developed athletes; therefore, further examination of the triple jump is warranted. The present study examined the phase ratios of collegiate triple jumpers to determine which technique was utilised by athletes and the relationship between phase lengths and actual distance jumped. Nine, collegiate triple jumpers were recorded during a regularly scheduled outdoor Track and Field competition. Trials were digitised to determine phase lengths for the longest and shortest triple jumps of each athlete. Pearson-r correlation and multiple regression analyses were completed to determine relationships of phase lengths to actual triple jump distance. Significant, positive correlations were found for the length of the hop ($r = 0.68$, $p = 0.044$) and step ($r = 0.90$, $p < 0.001$) phases to the longest actual triple jump length. The linear combination of the phase ratios was significantly related to the triple jump length; however, step length was found to be most heavily weighted, accounting for approximately 80% of the variance in triple jump length. Therefore, collegiate triple jumpers can maximise total triple jump length by minimising over-hopping and maximising the length of the step phase.
Key words: track and field, horizontal jump, effort distribution.

Introduction

The triple jump is one of two horizontal jumps in Track and Field competition, with the long jump being the other a more recognised event. The other horizontal jump, the triple jump, is widely considered to be a far more physiologically and technically demanding event due to the design of the competition, which contains three distinct ground contact phases, known as the hop, step, and jump (Hay, 1992; Hay & Miller, 1985). The optimal contribution of each phase to the triple jump has been a point of discussion for decades (Yu & Hay, 1996). Specifically, debate has centred on whether triple jumps should be first phase dominant (i.e. hop phase), third phase dominant (i.e. jump phase), or balanced (i.e. relatively equal hop and jump phases) (Hay, 1992; Hay & Miller, 1985).

In the pursuit of competition superiority and a competitive advantage, athletes and coaches have routinely turned to sport scientists to assist them in the progression of their triple jump performance (Hay, 1992, 1995). Based in large part on the research of Dr. James Hay, the use of a jump-dominated approach has been advocated for triple jumpers as it has been hypothesised that hop dominance, or excessive hop phase length, would be detrimental to the length of the successive phases and total triple jump length; however, this is largely more a result of a qualitative, logical argument for jump phase dominance rather than being based upon a strong, quantitative set of supporting data (Hay, 1992, 1995). Interestingly, all three techniques are utilised by elite competitors at the international level, with numerous world championships, Olympic medals, and world records utilising a mixture of the techniques (Fukashiro & Miyashita, 1983; Hay, 1992, 1999; Miller & Hay, 1986; Yu & Hay, 1996).

Based on published data of 73 elite triple jumpers at World Championships or Olympic competitions, approximately 48% of the athletes utilise a hop dominant technique, 44% utilise a balanced technique, and only 8% utilise a jump dominant approach (Brüggemann, Clayton, Fédération internationale d'athlétisme, & International Athletic, 1990; Foundation, 1990; Hay, 1999; Hay & Miller, 1985). When analysing Olympic competition triple jumps, Hay (1999) reported a mean actual triple jump distance of 16.57 metres (m), with phase distances of 5.95 m, 4.93 m, and 5.69 m for the hop, step, and jump phases, respectively, indicating the field utilised, on average, a balanced triple jump technique. When examining the top eight competitors at the 1996 Olympics, Hay (1999) reported four hop dominant jumpers, three balanced, and one jump dominant. The mean actual triple jump distances for the hop dominant group was 17.34 m, with mean phase distances of 6.43 m (i.e. hop), 5.31 m (i.e. step), and 5.60 m (i.e. jump) while the combined balanced and jump dominant groups displayed mean actual triple jump distances of 17.49 m and mean phase distances of 5.99 m (i.e. hop), 5.36 m (i.e. step), and 6.15 m (i.e. jump).

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It has been hypothesised that increases in individual phase lengths occur differently depending on the stage of technical and physiological development of the performer (Hay, 1992). Specifically, authors have previously postulated that athletes initially develop greater leg strength and power during initial stages of training. These increases seem to allow an athlete to better utilise landing forces during each contact phase. This would presumably result in an increased step length and subsequent total triple jump length (Hay, 1992). This hypothesis asserts that initial phase length changes are followed by increases in the length of the hop due to improved sprint and approach technique. These improvements are subsequently followed by increases in the length of the jump phase, which are thought to be brought about by changes in neurological factors related to force development. Each of these lead to an overall increase in total triple jump length (Hay, 1992).

Presently, the majority of published research on triple jump technique is with respect to the performance of elite international and Olympic competitors. In fact, to the knowledge of the authors of the present study, the only published study examining the phase ratios and effort distributions of collegiate or junior triple jumpers is approximately thirty years old and involves a mixture of collegiate and unattached athletes (Fukashiro, Iimoto, Kobayashi, & Miyashita, 1981). Likewise, the vast majority of the published scientific research on the triple jump is several decades old, with very little activity within the last decade. Still, the literature was left in an unresolved state with research studies disagreeing on the best technique to use during competition (Fukashiro et al., 1981; Hay, 1992, 1999; Hay & Miller, 1985; Miller & Hay, 1986).

Due to considerable physiological and technical differences between elite level competitors and most collegiate athletes, an investigation of the phase ratios of collegiate triple jumpers during competition is warranted (Fukashiro et al., 1981; Hay, 1999). Therefore, the purpose of this study was to examine the phase ratios of collegiate triple jumpers to determine if a relationship exists between collegiate triple jumping success, individual phase length contribution to total triple jump length, and phase-dominance. Because collegiate athletes are generally of lower technical and physical ability than elite or Olympic calibre athletes, which is the population primarily studied within the literature, it was hypothesised that the majority of the athletes would display a hop-dominant technique during the longest actual triple jumps. Likewise, it was hypothesised that athletes would display greater hop dominance during the shortest actual triple jumps as compared to the longest actual triple jumps. Specifically, it was hypothesised that the hop phase would contribute a greater percentage to the overall triple jump length during the shortest actual triple jump compared to the longest actual triple jump.

Materials & Methods

Data was collected during a single-day Track and Field competition occurring in the state of Louisiana. The session consisted of filming nine Division-one (D1) participants (n = 9) during a National Collegiate Athletic Association (NCAA) a competition in late March as part of the athlete's regularly scheduled outdoor Track and Field season. All attempts made by athletes during the preliminary and final rounds were videoed and used during data analysis. Researchers only observed and filmed the competition, without any interruption or alteration to the competition format. This event was open to a number of universities, and as such, schools from a broad geographical area were in attendance. Ethical approval to film the competition was granted by the Office of Research Compliance at the home institution of the principal investigator and coordinated with meet officials during the competition.

As is standard during competition, each athlete was given three attempts during the preliminary rounds and three more jump opportunities during finals. All nine participants that took part in the competition were eligible for the final rounds of competition, allowing for a maximum of six attempts per participant (for a total of 54 possible triple jumps). A total of 19 attempts were fouled by participants, with two participants also passing on a total four (4) attempts. These trials were removed prior to digitising, leaving a total of 31 legal attempts (out of a possible 54) for analysis. All participants registered at least two legal attempts during the competition. Only legal trials were utilised for analysis; however, the actual distance, defined as the horizontal distance from the toe of the take-off foot at hop take-off to the nearest mark in the sand, was utilised during data analysis. The NCAA defines a jump as foul, and hence not legal, if any of the following are true: phase order is not correct; take-off foot extends beyond the foul line; athlete runs through the foul line; during the course of landing, the athlete touches ground outside of the landing area; or the competitor employs any form of somersaulting during the trial before making contact with the landing area (National Collegiate Athletic Association., 2015).

All triple jumps were recorded with a single, high-speed digital camera (Casio EX-FH20 Exilim, Casio America, Dover, NJ, USA) recording at 210Hz and shuttered at 1/1000th of a second. The camera was placed away from the competition area so as to minimise interference with the competition and comply with NCAA standards. The camera maintained a perpendicular view of the runway with an approximately 25m view, allowing capture of the last stride of the approach and each phase of the triple jump, including the landing pit. Figure 1 provides an illustration of the competition environment and recording delimitations. Two 14 m x 0.0508 m Velcro strips of alternating white and black 0.50 m segments were stapled to each edge of the runway surface between the take-off board and landing pit (Hay, 1999). This assisted in determining appropriate linear scales and a fixed origin for the coordinate system during the data analysis.

Each legal attempt completed by an athlete was digitised (HU-M-AN, Version 6.0 2D, HMA Technology, Guelph, ON, Canada) to determine the actual distance jumped. Additional analyses were completed on the longest and shortest actual competition triple jumps for each athlete to determine the relative contribution of the hop, step, and jump phases. During each trial, the distance of each phase was determined by measuring the horizontal distance from the toe of the support foot prior to take-off, to the toe of the support foot, or closest mark in the sand at the subsequent ground contact (Hay, 1999). Phase dominance was accepted as a difference greater than 2% of the length of the dominant (i.e. largest) phase relative to the second longest phase (Hay, 1992, 1995, 1999). Stance contact time during each phase of support was determined from the cumulative time between touchdown and take-off. As described in previous research, touchdown was defined as the first frame showing the athlete regaining contact with the ground with the pertinent leg and take-off was defined as the first frame showing that athlete breaking contact with the ground with the take-off leg (Fukashiro et al., 1981; Hay, 1992, 1999; Hay & Miller, 1985; Miller & Hay, 1986; Yu, 2006; Yu & Hay, 1996).

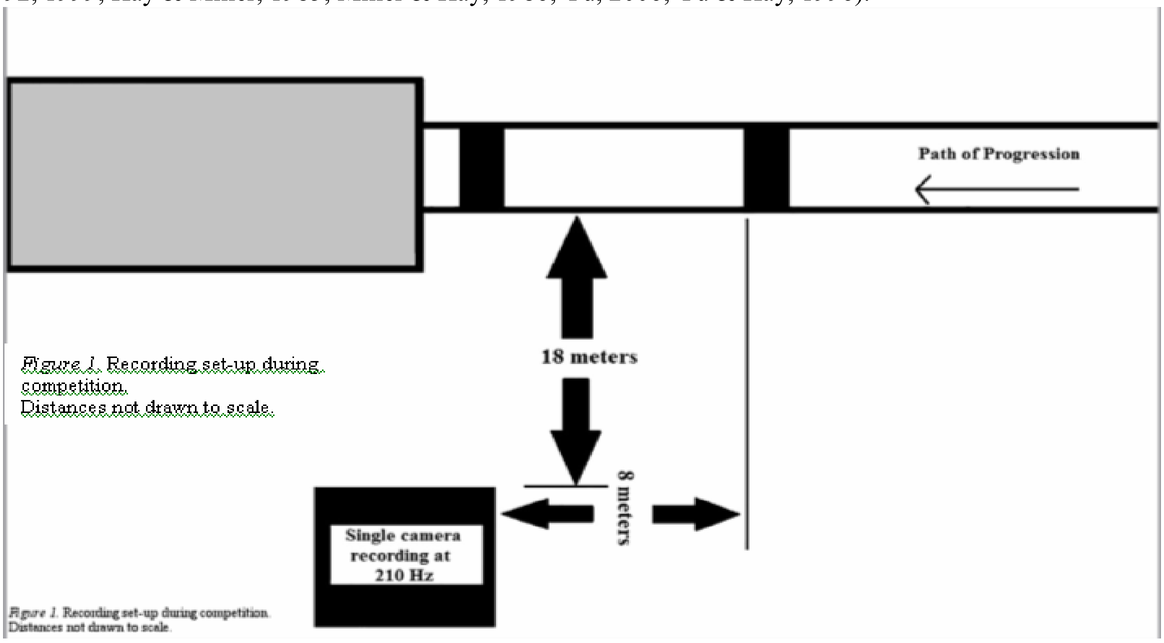

Fig. 1. Recording set-up during competition

A strong and significant correlation (r = 0.99, $p < 0.001$) was observed between the offical length of the maximum and shortest jumps, as reported during the competition, and the length of the maximum and shortest actual distance as measured during the digitising process (Table 1). A normality analysis for the longest actual triple jump lengths and lengths of the respective hop phases, step phases, and jump phases revealed that data for the nine participants was normally distributed ($p = 0.307$). Pearson product-moment correlation coefficients were calculated between the actual distance jumped of the longest triple jumps for each athlete and: distance of the hop phase; distance of the step phase; and distance of the jump phase. Finally, a multiple regression analysis was performed to determine the relative contribution of each phase to the overall triple jump. The alpha level was set *apriori* at $p < 0.05$. All statistical analyses were completed in SPSS v22 (IBM Corporation, New York, USA).

Participants	Longest Official Distance (m)	Longest Actual Distance (m)	Dominance	Hop %	Step %	Jump %	Shortest Official Distance (m)	Shortest Actual Distance (m)	Dominance	Hop %	Step %	Jump %
Jumper 1	12.99	13.12	Hop	36%	30%	34%	12.12	12.25	Hop	38%	31%	31%
Jumper 2	12.95	13.17	Hop	38%	27%	35%	12.34	12.52	Balanced	35%	30%	35%
Jumper 3	13.75	13.77	Jump	34%	28%	38%	12.96	13.30	Hop	36%	30%	34%
Jumper 4	14.19	14.27	Balanced	35%	30%	35%	13.94	14.17	Hop	37%	29%	33%
Jumper 5	14.38	14.44	Jump	34%	30%	36%	12.48	12.56	Hop	37%	30%	33%
Jumper 6	14.44	14.65	Balanced	35%	30%	35%	13.68	13.78	Hop	37%	31%	32%
Jumper 7	15.02	15.17	Hop	37%	31%	32%	14.57	14.83	Hop	39%	27%	34%
Jumper 8	14.56	14.67	Jump	33%	31%	36%	14.24	14.55	Balanced	34%	31%	35%
Jumper 9	14.18	14.50	Balanced	35%	32%	33%	12.06	12.17	Hop	42%	34%	24%
Mean	14.05	14.20		35%	30%	35%	13.15	13.35		37%	30%	32%
(±SD)	(0.69)	(0.70)		(1.6%)	(1.5%)	(1.8%)	(0.97)	(1.02)		(2.3 %)	(1.9%)	(3.4 %)

Results

The longest official distance, the longest actual distance, and the shortest actual distance were 14.05 ± 0.70 m, 14.20 ± 0.70 m, and 13.35 ±1.03 m, respectively (Table 1). All attempts were made with no wind or a slight headwind (mean = 0.62 m/s). Phase ratios for the longest triple jumps and shortest actual triple jumps are presented in Table 1. Actual lengths of each phase for the longest and shortest actual triple jump are presented in

Figure 2. Results of the present study indicate that three of the participants were hop-phase dominant, three were balanced, and three were jump-phase dominant during the longest actual jumps. During the shortest completed triple jumps, eight of the nine participants, shifted towards hop phase dominance, while the other two participants were classified as balanced. One of those participants (Jumper 8) was classified as balanced during both the longest and shortest triple jumps, while the other participant (Jumper 2) was actually classified as hop phase dominant during the longest triple jump.

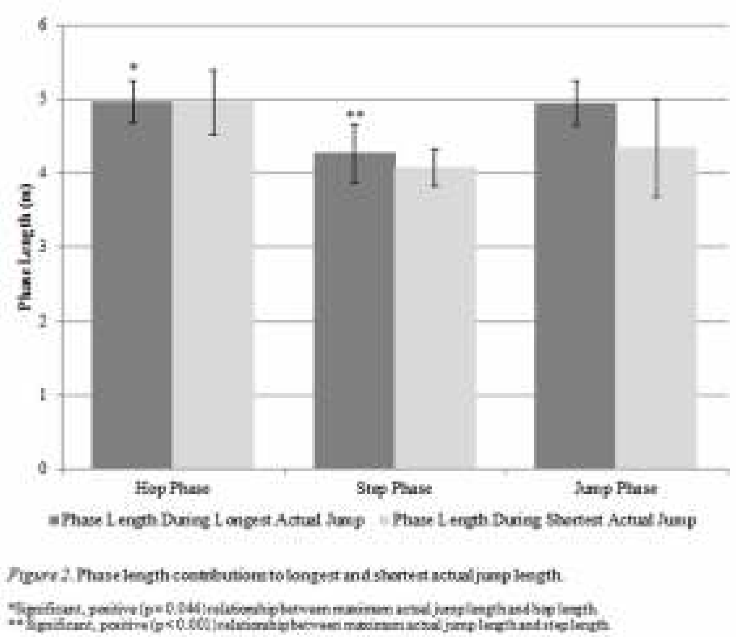

Fig. 2. Phase length contributions to longest and shortest actual length

A moderate and significant correlation (r = 0.68, p = 0.044) was found between the length of the hop phase and the overall length of the triple jump, while a very strong and significant relationship (r = 0.90, p < 0.001) was found between the length of the step phase and the overall length of the triple jump. There was no significant relationship between the length of the jump phase and the overall length of the triple jump.

Results of the regression analysis indicate that linear combination of the hop, step, and jump phases significantly (F (3, 8) = 2502.25, p < 0.001) contribute to actual triple jump length. The regression formula (Equation1) indicates that increases in the length of the step phase will contribute to greatest increase in actual triple jump length.

Equation 1:

Actual Jump Length = 0.413 + 0.974*hop + 1.061*step + 0.89*jump

Strong and significant negative correlations were found between stance contact time (Fig.3) for the length of the hop phase (r = -0.83, p = 0.005), length of the step phase (r = -0.77, p = 0.015), and the length of the jump phase (r = -0.73, p = 0.027) during the longest actual triple jump.

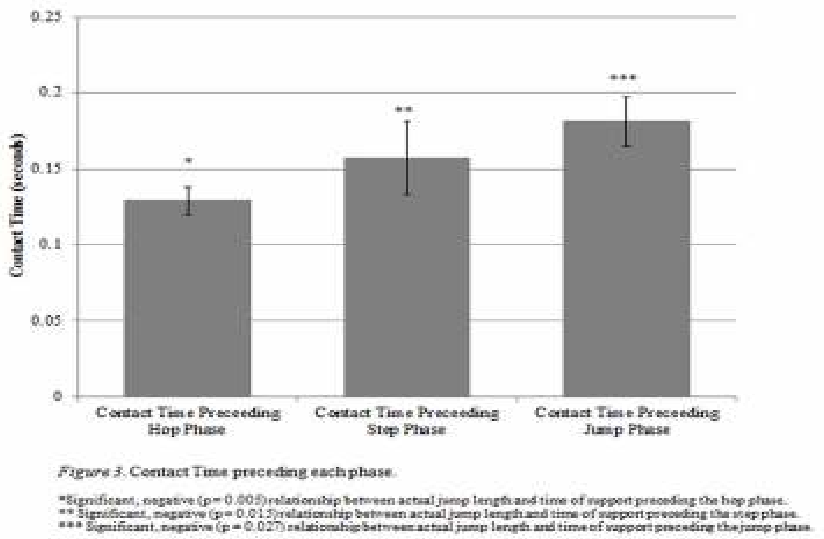

Fig. 3. Contact time proceding each phase

Discussion

Based upon the relative contribution of each phase to the longest actual triple jump (Figure 1), the participants of the present study were evenly split between hop dominant techniques, jump dominant techniques, or balanced techniques. This finding was unexpected considering the much shorter actual distance triple jumped reported in the present study as compared to the triple jump distances reported for elite triple jump athletes (Hay, 1999; Hay & Miller, 1985; Koh & Hay, 1990; Miller & Hay, 1986). During Olympic competition, phase lengths have been reported to be almost a metre greater in length during each phase as compared to the present study. As reported by Hay (1999), phase per cents were 36% ± 1.6%, 29.7% ± 1.6%, and 34.3% ± 1.4% for the hop, step, and jump phases, respectively, which are comparable to the findings of the present study. Furthermore, 49% of the participants were reported to have been hop-phase dominant, 44% of the participants were balanced, and only 7% were jump phase dominant (Hay, 1999). In a study by Fukashiro and colleagues (1981) which examined top Japanese triple jumpers, average hop phase distances (5.33m) were longer than the present study; however shorter step and jump phase distances observed in that study nearly eliminated any difference in overall triple jump length with respect to the present study.

The phase ratios of Fukashiro et al. (1981) resemble the results of Miller and Hay (1986), which examined elite triple jumpers at the U.S. National Championships. In the latter study, three of the four participants exhibited hop phase per cents in the range of 36-37% and jump phase per cents of 33%; however, the actual triple jump lengths were much longer than Fukashiro et al. (1981). Together, these results challenge the hypotheses of previous researchers that athletes shift towards jump-phase dominance as their technical and physiological development occurs (Hay, 1992; Miller & Hay, 1986; Yu & Hay, 1996). Rather, the present study suggests that athletes may be capable of developing balanced or jump dominant techniques early in a jumping career.

In the present study, significant, positive correlations were found between the longest actual triple jumps and hop phase length (r = 0.68, $p = 0.044$) as well as between the longest actual triple jumps and step phase length (r = 0.90, $p < 0.001$). These results are similar to the research by Fukashiro and colleagues (1981) which found significant positive correlations between the hop phase and the step phases, but no significance with regards to the length of the jump phase and overall triple jump length. Hay and Miller (1985) also found similar results with regards to the step phase (r = 0.50, $p < 0.10$), but found insignificant ($p > 0.10$) correlations between the length of the hop and jump phase. Based on their results and the earlier work of Fukashiro and colleagues (1981), it has been suggested that while the hop and jump phases contribute greater overall length to the actual triple jump, these phases contribute only a small amount of the variance in total length (15.2% and 11.6%, respectively) as compared to the step phase (Hay & Miller, 1985). The results of the present study support and expand this previous finding, indicating that collegiate triple jumpers also perform in a manner, in which the step phase accounted for approximately 81% (r = 0.90, $p < 0.001$) of the variance of the longest actual triple jump length.

As a result, the greater the emphasis the athlete puts into the step phase the better the overall jump. This statement appears to discourage high per cent hop phases, especially with less developed athletes, as greater vertical ground reaction forces during the landing of the hop phase decrease the ability of an athlete to exert maximal effort, resulting in greater losses in horizontal velocity, during the take-off of the step phase. The present study would support these as hypotheses, as all but one participant increased the relative contribution of the hop phase during their shortest actual triple jumps as compared to their longest actual triple jumps (Table 1). Considerable changes were observed in both the relative and absolute values of the jump phase during the shortest triple jumps in which participants tended to increase the contribution of the hop phase while decreasing the contribution of the jump phase. This would appear to support the case that step length, and not step per cent, is highly correlated to overall triple jump length.

In previous published projects on the triple jump, the time of support increased with each successive period of support, which is likely due to the decrease in horizontal velocity with each subsequent phase. Even though touchdown and take-off were defined in a similar manner, contact times were routinely shorter in the present study, though by only a few thousandths of second, than those of Hay and Miller (1985). These differences may be attributed to the higher frame rate used in the present study (210 Hz) than was utilised in all three of the earlier studies (100 Hz). In the present study, significant negative correlations were found between contact time during each phase and overall triple jump length. These results are similar to those found by other researchers (Fukashiro et al., 1981; Fukashiro & Miyashita, 1983; Hay, 1992, 1999; Hay & Miller, 1985; Miller & Hay, 1986). However, care should be taken when interpreting these relationships as this finding may not necessarily imply a direct relationship indicating that ground contact time should be actively minimised by jumpers; rather the negative correlation is likely a result of relationships between ground contact time and the velocity of the approach (Koh & Hay, 1990). Furthermore, the periods of support preceding the step and jump phases involve significantly larger changes in vertical force than during the hop phase. If the support phase preceding the step or jump phases are too short, there may not be enough time to allow a participant to produce a sufficiently large enough change in vertical velocity (Koh & Hay, 1990).

The results of this study raise some questions regarding the development of an optimised technique over the course of an athlete's career. In the present study, participants were evenly split between the uses of a hop-dominant, jump-dominant, or balanced technique, despite their lower level of development as compared to the participants of other studies. The present study demonstrated the highest ratio of jump-dominant observed anywhere in the literature. Presently, there is no published research regarding the phase ratios of American collegiate triple jumpers and the only published research involving collegiate triple jumpers of any kind is over thirty years old (Fukashiro et al., 1981). Considering the difference in the actual triple jump length of the present study as compared to the results of Fukashiro and colleagues (1981), it would appear that the results of the current study are more likely attributable to a shift in coaching philosophy, rather than improvements in conditioning protocols. Additional longitudinal research is necessary in which the best triple jumps of the same athletes are analysed over a period of several years in order to track changes in technique as their physiological development progresses.

A noted limitation of the present study was the collection of kinematic data through the use of a single camera. As such, parallax could be a concern given the distance covered by the athletes during the execution of the jumps. Furthermore, as only a horizontal scale was utilised during the digitising process, determination of additional variables of interest (i.e. vertical velocity) is limited. Given these limitations, the present study did utilise a similar protocol as previously reported studies. Likewise, results of the present study appear to be appear in line with the findings of previous research reported research (Fukashiro et al., 1981; Fukashiro & Miyashita, 1983; Hay, 1992, 1999; Hay & Miller, 1985; Miller & Hay, 1986). Though the distances reported in the present study are smaller in magnitude as compared to previous studies, this is likely due to the calibre of the participants; specifically, previous research has largely focused on the elite level triple jumpers whereas the present study focused on collegiate athletes. Finally, a very strong and significant correlation was observed between the officially reported competition distances and the digitised distances of the jumpers.

Conclusions

Combined with the results of previous studies, the results of the present study suggest there is not enough support for the exclusive use of a jump-dominated technique; however, the results do appear to support that the placement of too much effort on the hop phase will have a negative effect on total triple jump length. In summary, results of the present study provide insight into several factors that should be examined when focusing on the development of the maximum triple jump length for collegiate triple jump athletes. First, excessive influence should not be placed on the length of the hop phase by attempting to maximise vertical velocity; rather, the optimal technique will develop from focusing on the maintenance of horizontal velocity during the earlier support phases. Likewise, over-hopping will have a negative effect on the overall length of the triple jump and the length of subsequent phases. As opposed to the hop phase, the actual length of the triple jump is highly correlated to the actual length of the step phase, and as such, a jumper should place maximal effort into lengthening the step phase. This can be achieved by minimising losses in horizontal velocity during the support phase preceding the step phase. Finally, a jumper should not try to actively minimise ground contact time as this may result in an inability to properly manage changes in the vertical ground reaction forces during the support phases. Rather, ground contact will be minimised by focusing on maintaining horizontal velocity from the approach through the three support phases.

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References

Brüggemann, G.-P., Clayton, J., Fédération internationale d'athlétisme, a., & International Athletic, F. (1990). *Scientific research project at the games of the XXIV olympiad, Seoul 1988 : final report : [biomechanical analyses of the jumping events, time analyses of the sprint and hurdle events]*. pp. 306-362].

Foundation, I. A. (1990). *Scientific Report on the Second IAAF World Championships in Athletics, Rome, 1987*: International Athletic Foundation. pp. 1 - 67.

Fukashiro, S., Iimoto, Y., Kobayashi, H., & Miyashita, M. (1981). A biomechanical study of the triple jump. *Medicine & Science in Sports & Exercise, 13*(4), 233-237.

Fukashiro, S., & Miyashita, M. (1983). An estimation of the velocities of three take-off phases in 18-m triple jump. *Medicine & Science in Sports & Exercise, 15*(4), 309-312.

Hay, J. (1992). The biomechanics of the triple jump: a review. *Journal of Sports Sciences, 10*(4), 343-378.

Hay, J. (1995). The case for a jump-dominated technique in the triple jump. *Track Coach, 132,* 4042-4048.

Hay, J. (1999). Effort distribution and performance of Olympic triple jumpers. *Journal of Applied Biomechanics, 15*, 36-51.

Hay, J., & Miller, J. A. (1985). Techniques used in the triple jump. *International Journal of Sport Biomechanics, 1*, 185-196.

Koh, T. J., & Hay, J. G. (1990). Landing leg motion and performance in the horizontal jumpers II: the triple jump. *International Journal of Sport Biomechanics, 6*, 361-373.

Miller, J. A., & Hay, J. G. (1986). Kinematics of a world record and other world-class performances in the triple jump. *International Journal of Sport Biomechanics, 2*, 272-288.

National Collegiate Athletic Association. (2015). NCAA men's and women's track and field and cross country rules (pp. 76-77). Overland Park, Kan.: National Collegiate Athletic Association.

Yu, B. (2006). Effects of phase ratio on the performance in the triple jump. *Journal of Biomechanics,* 39(S1), S184.

Yu, B., & Hay, J. G. (1996). Optimum phase ratio in the triple jump. *Journal of Biomechanics, 29*(10), 1283-1289. doi: 0021929096000486 [pii]