COMPARATIVE BIOMECHANICAL ANALYSIS OF A FEMALE HAMMER THROW ATHLETE FOR BACK-TO-BACK AMERICAN RECORD YEARS

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Hammer athletes must optimize performance variables to maximize their official distance. Analysis of key performance variables might explain how the subject improved an American record year in 2018 to another record in 2019. A 3-D analysis was performed on trial videos from 2018 and 2019. Release height, release velocity, release angle, and hip-shoulder separation were compared among years and throws, and their relationship with official distance was assessed. Release height ($p < 0.01$) and release angle ($p < 0.01$) were more consistent in 2019 than 2018. The relationships among official distance, release height ($p = 0.06$), and hip-shoulder separation ($p = 0.04$) were different between years. The efficient use of hip-shoulder separation could be responsible for the increase in official distance between years.

KEYWORDS: Hammer throw, Performance, Improvement, Record.

INTRODUCTION: The objective of the hammer throw in track & field is to throw the hammer the maximum possible distance while adhering to the rules and regulations of the sport (Brice et al., 2018). Release velocity, release angle, and release height are all significant factors in the distance an athlete throws, but the exact combination of values, as well as the method for achieving optimal values for these, vary per athlete (Bartonietz et al., 1997). The method that athletes use to achieve maximum distance does not matter. Therefore, it is advantageous for athletes to use optimal physics and training approaches to maximize distance (Judge et al., 2008).

A female hammer throw athlete set the American record and threw the fourth-best throw of all-time in 2018, with an official distance of 78.12m. The subject bested their record in 2019 at the same event, with an official distance of 78.24m. The subject's ability to improve on one of the best throws of all time presents a unique opportunity to analyze how an athlete, at the pinnacle of their sport, found a way to improve on one of the best throws in history. Assessing how the subject improved is important for understanding the role key performance variables play in the continual improvement of elite-level athletes.

Key variables for successful hammer throw performance have been investigated in prior research: hip-shoulder separation angle difference of the 4th right foot touchdown and release (HSSA), release height, release velocity, and release angle (Judge et al. 2008; Konz & Hunter 2015; Brice et al. 2018; and Bartonietz, 1995). Most research on the hammer throw has investigated how specific variables impact distance, but there is a dearth of research investigating the combined effect of multiple performance variables and distance. Research on the consistency of throwing mechanics in various throwing-sports indicates that decreasing variability in throwing mechanics improves performance (Dai et al., 2013; Whiteside et al., 2015). While the effect of biomechanical consistency has not been researched on hammer throw athletes, its potential impact on performance success makes it a parameter of interest for this study. The purpose of this study was to determine the changes in key performance variables, and their impact on official distance, in back-to-back American Record years for one female hammer throw athlete at the USATF Outdoor Championships. We hypothesize that there will be similar consistency in HSSA, release height, release velocity, and release angle of throws between 2018 and 2019, but the relationship between official distance and HSSA, release height, release velocity, and release angle will see a positive change between throws in 2018 and 2019. The determination of differences in these key variables will be of interest to elite-level hammer throw athletes and coaches, as these values could provide evidence that improvements can still be made through refinement and utilization of different performance factors.

METHODS: The subject studied was an American Track & Field hammer throw athlete competing in the 2018 and 2019 USATF Outdoor Championships. The subject was a 27 y/o female, that weighed 108 kg and was 1.72 m tall. Two Sony RX10 III (Sony DSC-RX10M3; Sony, 2019) cameras and a 24-point calibration frame were set up and recorded before and after recording the athlete's throws at both events. 2-D videos were taken using the two cameras. The first camera was positioned outside the ring, behind the net, facing the flight path trajectory. The second camera was positioned outside of the ring, behind the net, facing perpendicular to the flight path trajectory. Videos from both cameras were recorded simultaneously of the throws. Four (4) fair throws were recorded in 2018, and five (5) fair throws were recorded in 2019. Each camera recorded 2-D videos that were manually digitized using a 23-point marker set (Vicon Motus 10.0.0.55125h; Vicon Motion Systems, Inc., 2012). The digitized 2-D videos were combined and analyzed using Direct Linear Transformation in MotionSoft (MS3D-2016, MotionSoft Inc., 2016). HSSA, release height, release velocity, and release angle were determined and compared between years and between record throws. The release height was calculated as the height of the junction between the hammer's handle and chain in reference to the ground upon release. The release velocity was calculated as the linear speed of the hammer upon release. The release angle was calculated as the angle at which the hammer was released in reference to the horizontal. HSSA was calculated from the difference in shoulder alignment compared to alignment, where HSSA was positive when the pelvis was leading the shoulders. Coefficients of variation (CV) for the measured variables were calculated as the mean divided by the standard deviation for the 2018 and 2019 throws and then compared using an F-test. Linear regression analysis was performed to determine the relationship between each measured variable and official distance for 2018 and 2019. The significance of the performance variable relationships to official distance was compared between years using a paired-samples t-test. Direct comparisons were made between measures for key variables between the two record throws. Statistical significance was set a priori as alpha = 0.1.

RESULTS: The average release height (+16.22%), release velocity (+1.37%), release angle (+11.48%), and HSSA (+6.93%) increased from 2018 to 2019 (Table 1). Release height (+27.72%), release angle (+3.17%), and HSSA (+39.41%) increased, while release velocity (-1.02%) decreased, from the 2018 record throw to the 2019 record throw (Table 1).
The release height for throws in 2018 had significantly more variability than for throws in 2019 (2018, CV = 50.37%, 2019, CV = 6.99%, $F(4,3) = 0.23$, $p < 0.001$). There was a significant difference in the relationship between release heights to official distance in 2018 and 2019, where release heights and thrown distance had a negative relationship in 2018, and release heights and official distance had a positive relationship in 2019 (2018 = -2.02 ± 2.12, 2019 = 4.26 ± 6.36, $t = 3.6$, $p = 0.06$) (Figure 1).
The variability in release velocity was similarly low between 2018 and 2019 throws (2018, CV = 2.20%, 2019, CV = 1.26%, $F(4,3) = 0.33$, $p = 0.31$). There was no significant difference in the relationship between release velocities to official distance in 2018 and 2019, where release velocities and official distance had a positive relationship in both 2018 and 2019 (2018 = 1.65 ± 1.68, 2019 = 1.28 ± 1.32, $t = 4.3$, $p = 0.62$) (Figure 2).
The release angle for throws in 2018 had significantly more variability than for throws in 2019 (2018, CV = 18.39%, 2019, CV = 0.70%, $F(4,3) = 0.002$, $p < 0.001$). There was no significant difference in the relationship between release angles to official distance in 2018 and 2019, where release angles and official distance had a negative relationship in 2018, and release angles and official distance had a positive relationship in 2019 (2018 = -0.01 ± 0.2, 2019 = 0.77 ± 1.94, $t = 0.79$ $p = 0.46$) (Figure 1).
The variability in HSSA was similarly high between 2018 and 2019 throws (2018, CV = 31.89%, 2019, CV = 28.47%, $F(4,3) = 0.81$, $p = 0.81$). There was a significant difference in the relationship between HSSA to official distance in 2018 and 2019, where HSSA and official distance had a positive relationship in both 2018 and 2019 (2018 = 0.1 ± 0.05, 2019 = 0.02 ± 0.04, $t = 2.6$, $p = 0.04$) (Figure 2).

Table 1. Measures of performance variables between 2018 and 2019 Championships.

	Release Height (m)		Release Velocity (m/s)		Release Angle (deg)		HSSA (deg)	
Year	2018	2019	2018	2019	2018	2019	2018	2019
Mean	1.01	1.17	28.75	29.14	36.14	40.29	47.29	50.57
(SD)	(0.51)	(0.08)	(0.63)	(0.37)	(6.64)	(0.28)	(15.08)	(14.4)
Record	1.01	1.29	29.49	29.19	39.09	40.33	42.2	58.83

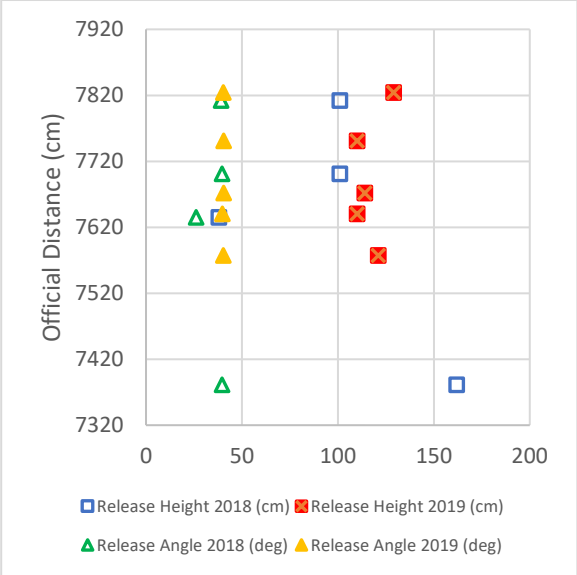

Figure 1. Comparison of the Relationship Between Official Distance and Release Height and Release Angle for 2018 and 2019.

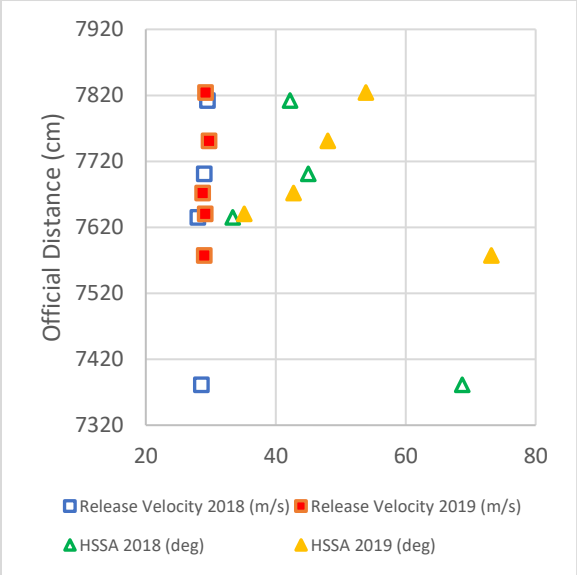

Figure 2. Comparison of the Relationship Between Official Distance and Release Velocity and HSSA for 2018 and 2019.

DISCUSSION: We hypothesized that there would be similar consistency in HSSA, release height, release velocity, and release angle of throws between 2018 and 2019, but the relationship between official distance and HSSA, release height, release velocity, and release angle would see a positive change between throws in 2018 and 2019. Our results predominantly aligned with our hypothesis, as release velocity and HSSA possessed similar consistency between 2018 and 2019 throws, and there was a positive change in the relationship between official distance and HSSA and release height from 2018 to 2019. There was, however, a significant improvement from 2018 to 2019 in the consistency of release height and release angle, and no change relationship between official distance to release velocity and release angle from 2018 to 2019. These results indicate that improved release height and angle consistency, as well as how HSSA and release height were utilized, could have been factors in the improved average thrown distance.

The subject was able to throw a farther distance for their 2019 record throw, compared to their 2018 record throw, despite having a slower release velocity. The improved distance despite slower release velocity could be due to the utilization of HSSA to generate velocity instead of reliance on strength, as well as an increased release height. The subject increased their HSSA by 3.28°, and positively changed the effect HSSA had on official distance from 2018 to 2019. The subject decreased the variability in their release height and positively changed the effect release height had on official distance from 2018 to 2019. Improvements in HSSA and release height could be a result of technique and strength training. Movement consistency is necessary for performance success; however, movement patterns must adapt to internal and external environmental changes for performance consistency and continued improvement (Kudo & Ohtsuki, 2008). Therefore, future improvement may be dependent on how variables are utilized instead of further increases in consistency.

Athletes must find the best way to utilize different performance variables to maximize their thrown distance (Brice et al., 2018; Judge et al., 2008). Release height, release velocity, and

release angle, which are the main factors affecting official distance, were analyzed (Dapena et al., 2003). However, underlying variables, such as duration of support phases, changes in hammer speed during support phases, and vertical hammer position at touchdown and takeoff phases, have all been shown to contribute to release height, release velocity, and release angle, but were not analyzed due to the scope of the study (Judge et al., 2008; Konz & Hunter, 2015). More in-depth analysis of underlying linear and angular motion variables that cause the increase in key variables might be needed to better explain what the subject did to the increase in official distance.

This study did possess limitations. The limited sample size could be related to the lack of significance when comparing relationships between distance and key throwing variables. The small sample of competition trials could affect the ability to determine a true change in performance variable consistency. Digitization accuracy and reliability were not assessed, as the assumption is that the individuals digitizing the throws were consistent in their identification of landmarks. However, the assumption of digitization consistency could potentially lead to measurement error. Differences in weather at the venue between 2018 and 2019 could have resulted in differences in aerodynamics, affecting official distance (Hunter, 2005).

CONCLUSION: There was a 43.38% and 17.69% increase in consistency for release height and angle from 2018 to 2019. The relationship between official distance and release height (2018 = -2.02 ± 2.12, 2019 = 4.26 ± 6.36) and HSSA (2018 = 0.1 ± 0.05, 2019 = 0.02 ± 0.04) changed from 2018 to 2019, where release height and HSSA had a positive relationship with official distance. Slight increases in all analyzed performance variables and improvements in how release height and HSSA were utilized may have affected the increase in official distance. The subject potentially bested their record by relying more on their technique and better utilizing performance variables.

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