ORIGINAL ARTICLE

Relationships between throwing distance and physical strength in female hammer throw: Estimating physical strength requirement corresponding to throwing distance

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ABSTRACT

The purpose of this study was to clarify the relationships between female hammer throwers' physical strength and their throwing performance and to create standard values corresponding to throwing distance. Eighty-two female hammer throwers, with the throwing distance ranging from 30.31 to 63.82 meters, participated in this study. The questionnaire was designed to collect data on physical strength. Pearson's product-rate correlation coefficient was used to examine the relationship between each item and the throwing distance. A single regression analysis was performed with each item which was significantly correlated to the throwing distance as the dependent variable and the throwing distance as the independent variable to estimate the standard values corresponding to throwing distance. The results showed that all physical strength variables, except for 30 m sprint, were significantly correlated with the throwing distance, with weight training variables having the higher correlation coefficients. In addition, standard values corresponding to throwing distance were obtained using a single regression analysis.
Keywords: Performance analysis, Athletics, Throwing events, Body weight, Weight training.

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INTRODUCTION

The hammer throw is one of the four throwing events in track and field, alongside the shot put, discus throw, and javelin throw. Athletes throw the hammer in a circle with a diameter of 2.135 meters. Male and female throwers use hammer weighting 7.26 g and 4.0 kg, respectively, with lengths ranging from 1.175 to 1.215 meters. The factors that determine the throwing distance are the initial velocity at release, the release angle, and the release height. Previous studies have reported that the initial velocity at release has the greatest impact on the throwing distance (Gutiérrez et al., 2002; Isele and Nixdorf, 2010). The hammer throw is a complex movement characterized by a spatial structure that involves two or three preparatory winds of the hammer, followed by three, four, or five turns, while simultaneously the thrower-hammer system moves lineally across the throwing circle to achieve maximum final velocity at release (Gutiérrez et al., 2002). Furthermore, the hammer throw is one of strength-related sports, which has characteristics of a high traction force during throwing motion (Brice et al. 2011; Lavellee and Balam, 2010; Murofushi et al., 2005; Okamoto, 2007). Silvester (2002) also stated that muscular power plays a crucial role in generating momentum and energy for achieving longer throwing distance. Consequently, hammer throwers need to possess muscle strength and the ability to generate instantaneous force to withstand this load and accelerate the hammer (Hirose et al., 2013).

Speed, strength, endurance, flexibility and coordination of various physical strengths are essential for achieving higher performance. Especially, high-level performance in track and field heavily relies on strength (Judge, 2014). Several studies have investigated the relationships between physical strength and throwing performance. For example, in the indoor weight throw, which has a significantly correlation with hammer throw performance (Babbitt, 2017), a positive correlation was found between 1 repetition maximum (1RM) squat and performance in both male and female athletes (Judge et al., 2011). Terzis et al. (2007) reported 1RM squat and 1RM bench press were significantly correlated with shot put performance. Similarly, strong correlations were found between 1RM power snatch and the throwing distance achieved in shot put and weight throw (Stone et al., 2003). Regarding the hammer throw, a survey conducted in nine male hammer throwers revealed significant correlations between various factors such as 1RM clean, kettlebell throwing with one and two turns, standing long jump, standing triple jump, overhead shot throw, total score of the TEST QUADRATHLON (Jones et al., 1987), and the throwing distance (Hirose et al., 2013). However, there is a lack of studies investigated the relationships between physical strength and the throwing distance specifically in females, and most previous studies had small sample sizes.

In coaching, to improve athletes' performance, it is effective to follow a training cycle that includes understanding the structure of sports performance and the current situation, setting goals and tasks, developing training plans to solve the problems, training the athletes, and evaluating/diagnosing their progress (Zushi, 2014). Gambetta (2014a) also emphasized the importance of adhering to periodization processes, which encompass a systematic approach, a strategy to distribute training loads in relation to competition goals, a defined structure of progression, a sequential building-block approach, a predetermined time frame for execution of the plan, comprehensive coverage of all training components, the pursuit of specific competition goals, acknowledgement of the undulatory nature of the adaptive process, systematic manipulation of the variables of volume, intensity and density, as well as a method for monitoring training and evaluating competition results. Notably, testing and evaluation of athletes' biomotor abilities, which is an important part of the training plan (Gambetta, 2014a), requires clear standard values as a reference. To evaluate athletes' strength, various tests and scoring tables have been developed. In the case of track and field, "*Scoring for Biomotor Test Battery*" is presented for six different tests, and these indicators are useful for objective assessment of comprehensive fitness levels (Gambetta, 2014b). In recent years, some studies have been conducted to create standard values of physical training (such as the bench press, the standing long jump, 30 m sprint, etc.) in male discus and javelin throw (Maeda et al., 2018, 2019). These standard values provide practical information for setting training goals and evaluating/diagnosing training results. Thus, creating standard values corresponding to throwing distance can be useful in coaching in female hammer throw.

Many sports exhibits sex-related differences in technique, and the hammer throw is no exception. Numerous studies investigated sex-related differences in the hammer throw technique (Bartnietz et al., 1997; Hay, 1993; Konz and Hunter, 2015; Pavlović, 2020). Takanashi et al. (2021) argued that female discus throwers' training regimens were often based on the characteristics of their male counterparts, and the same can be said for the hammer throw. Therefore, the purpose of this study was to clarify the relationships between female hammer throwers' physical strength and their throwing performance and to create standard values corresponding to throwing distance. These insights also could inform training programs, talent identification, and performance enhancement strategies in female hammer throwers.

METHODS

Participants

Eighty-two female hammer throwers, with the throwing distance ranging from 30.31 to 63.82 meters, participated in this study. Regarding the inclusion/exclusion criteria of the participants recruitment procedure, throwers whose official throwing record exceeds 30 meters were chosen. We have directly contacted to coaches/throwers in Japan and ask for research cooperation. The survey was conducted via a paper or online questionnaire (Google form, Google Inc.). The questionnaire was designed to collect data on physical strength. The purpose and contents of the research were explained to all participants through the questionnaire. Each participant provided signed consent for the participation and for the publication of this. This study was approved by the ethics committee of Kyoto University of Advanced Science (No. 21-506).

Measures and procedures

Based on previous research (Hirose et al., 2013; Maeda et al., 2018, 2019) and training practicality, the following variables related to physique and physical strength were investigated: 1) height, 2) weight, 3) arm span, 4) grip strength of both sides, 5) full squat, 6) bench press, 7) snatch, 8) clean, 9) deadlift, 10) 30 m sprint, 11) 50 m sprint, 12) standing long jump, 13) standing triple jump, 14) standing quintuple jump, 15) overhead back toss with a shot (4.0 kg), 16) underhand forward throw with a shot (4.0 kg), 17) overhead back toss with a shot (2.721 kg), 18) underhand forward throw with a shot (2.721 kg), 19) throwing distance in hammer throw. For the variables from full squat to deadlift, we obtained the 1RM, while for the other variables, we investigated the participants' personal best records. We categorized these variables as follows: physique variables (1-3), physical strength variables (4-18), weight training variables (4-18), sprint variables (10-11), jumping variables (12-14), and throwing variables (15-18).

Measurement methods were the same as in previous studies (Maeda et al., 2018, 2019). For 1RMs of snatch and clean, lifting the barbell from either the ground or hang position was allowed, and the use of straps assisting grip was permitted. The times of the 30 m and 50 m sprints were measured manually, and participants could start from either a crouching or standing position. The records for the standing long jump, standing triple jump, and standing quintuple jump were the distance between the take-off and landing points of the participants. The overhead and underhand shot throws were performed by throwing from either on the stop board or ground.

Statistical analysis

Pearson's product-rate correlation coefficient was used to examine the relationship between each item and the throwing distance. A single regression analysis was performed with each item which was significantly correlated to the throwing distance as the dependent variable and the throwing distance as the independent variable to estimate the standard values corresponding to throwing distance. All statical analyses were conducted using SPSS 26.0 for Mac, and the significance level was set at 5%.

RESULTS

Table 1 shows the mean value, standard deviations, maximum and minimum values. The mean value of sample size was 54.4 ± 18.3 (Min.: n = 23, Max.: n = 81). All scattergrams are given in Figure 1. Significant correlations were found between the throwing distance and weight (r = .39, $p < .001$), grip strength (right: r = .44, $p < .001$, left: r = .47, $p < .001$), bench press (r = .56, $p < .001$), full squat (r = .59, $p < .001$), snatch (r = .79, $p < .001$), clean (r = .66, $p < .001$), deadlift (r = .53, $p < .001$), 50 m sprint (r = -.29, p = .04), standing long jump (r = .40, $p < .001$), standing triple jump (r = .61 p = .001), standing quintuple jump (r = 40, $p < .001$), overhead back toss with a shot (4.0 kg) (r = .62, $p < .001$), underhand forward throw with a shot (4.0 kg) (r = .61, $p < .001$), overhead back toss with a shot (2.721 kg) (r = .53, $p = .01$) and underhand forward throw with a shot (2.721 kg) (r = .47, $p = .01$). Table 2 shows the 95% confidence intervals of correlation coefficients with record. All correlation coefficients were within the 95% confidence intervals. Table 3 demonstrates the regression equations used to obtain the standard values corresponding to the throwing distance, coefficients of determination (R^2) and standard errors of each regression equation. Coefficients of determination were ranging from .07 (50 m sprint) to .62 (snatch). Table 4 shows the standard values corresponding the throwing distance (from 30 m to 80 m). In this study, we estimated the standard values for physical strength variables, while the standard values for physique variables were not calculated.

Table 1. Mean value, standard deviations, maximum and minimum values for all variables.

		Mean	SD	Max.	Min.
Record	(m)	46.72	6.90	63.82	30.31
Height	(cm)	161.6	5.9	181	143
Weight	(kg)	65.8	7.0	85	53
Arm span	(cm)	163.6	7.7	191	147
Grip strength: Right	(kg)	39.9	6.9	54	26
Grip strength: Left	(kg)	38.2	6.4	55	27
Full squat	(kg)	94.2	23.4	140	55
Bench press	(kg)	63.0	18.2	115	30
Snatch	(kg)	47.9	12.2	70	12
Clean	(kg)	66.8	16.8	105	35
Deadlift	(kg)	111.8	33.0	200	50
30m sprint	(s)	4.8	0.2	4.26	5.11
50m sprint	(s)	7.4	0.4	6.7	9
Standing long jump	(cm)	216.8	18.8	265	150
Standing triple jump	(m)	6.3	0.6	7.9	5
Standing quintuple jump	(m)	11.0	0.9	13.05	9
Overhead back toss with a shot: 4.0kg	(m)	11.7	1.8	16	9
Underhand forward throw with a shot: 4.0kg	(m)	10.9	1.4	14	8
Overhead back toss with a shot: 2.721kg	(m)	13.3	1.9	17.3	10.04
Underhand forward throw with a shot: 2.721kg	(m)	12.6	1.6	15.5	9.7

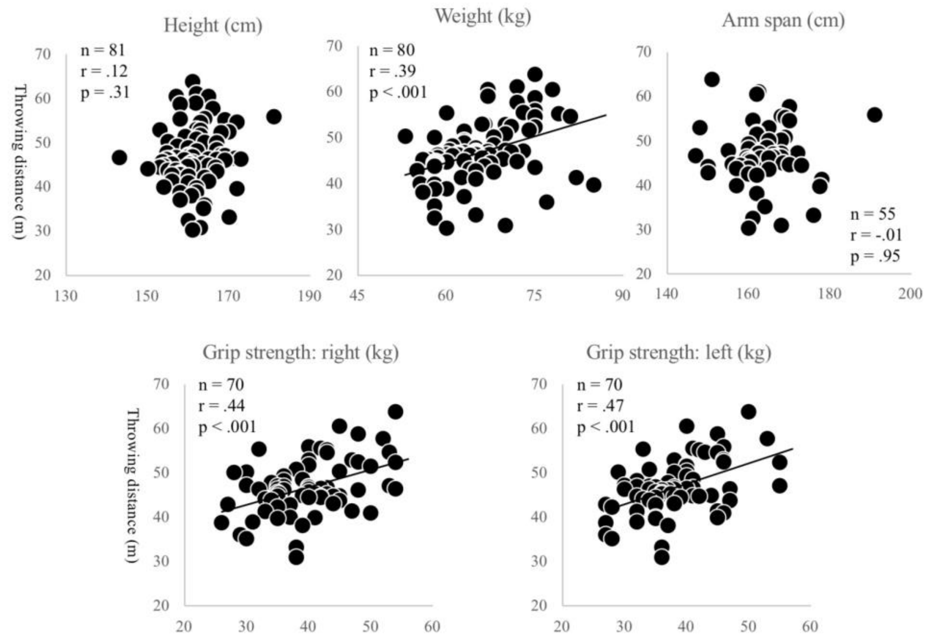

Figure 1a. Relationship between physical strength and throwing distance.

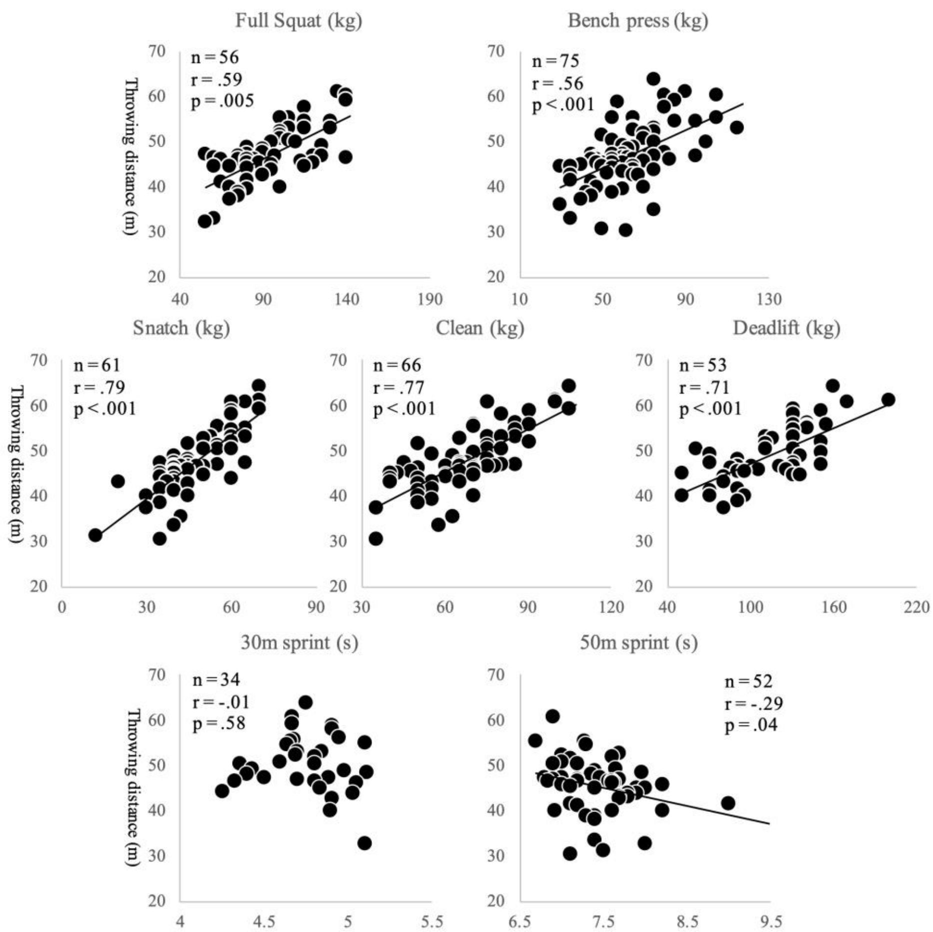

Figure 1b. Relationships between physical strength and throwing distance.

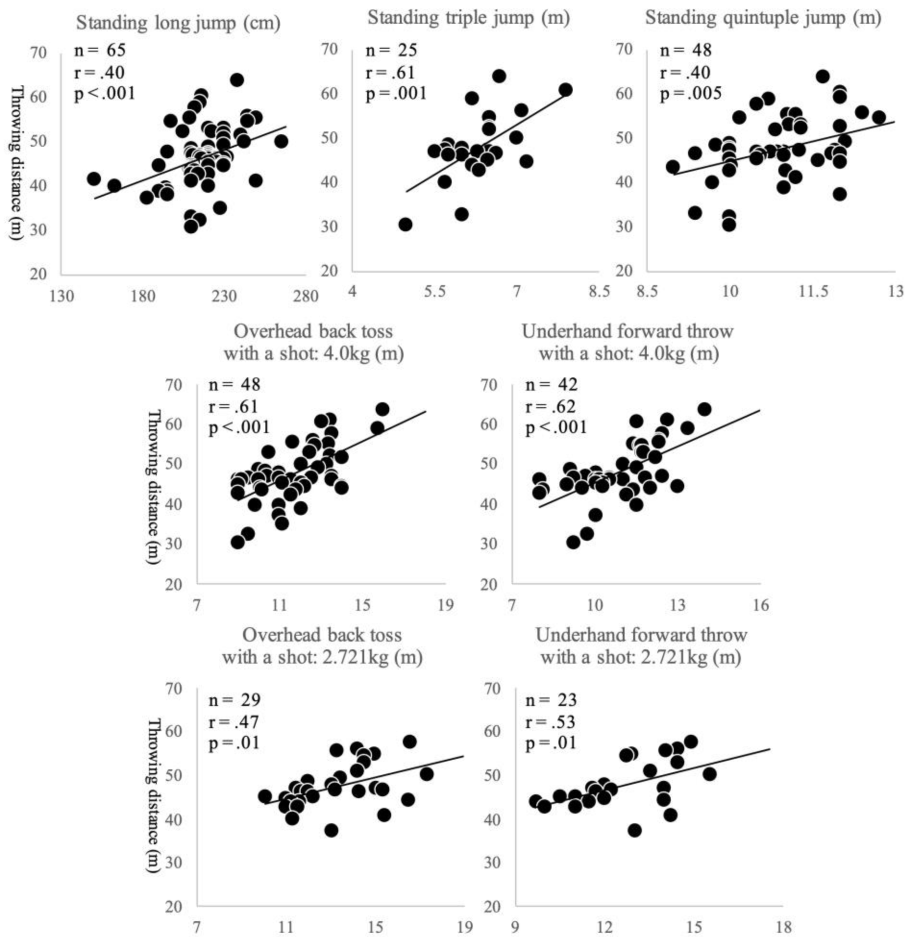

Figure 1c. Relationships between physical strength and throwing distance.

Table 2. 95% confidence intervals of correlation coefficients with record.

	Correlation Coefficient with Record	95% CIs
Height	0.12	-0.11 to 0.33
Weight	0.39	0.18 to 0.56
Arm span	-0.01	-0.27 to 0.36
Grip strength: Right	0.44	0.22 to 0.61
Grip strength: Left	0.47	0.26 to 0.63
Full squat	0.69	0.52 to 0.80
Bench press	0.56	0.38 to 0.69
Snatch	0.79	0.67 to 0.87
Clean	0.77	0.64 to 0.85
Deadlift	0.71	0.54 to 0.82
30m sprint	-0.10	-0.42 to 0.25
50m sprint	-0.29	-0.52 to -0.01
Standing long jump	0.40	0.17 to 0.58
Standing triple jump	0.61	0.39 to 0.76
Standing quintuple jump	0.40	0.13 to 0.61
Overhead back toss with a shot: 4.0kg	0.61	0.39 to 0.76
Underhand forward throw with a shot: 4.0kg	0.62	0.38 to 0.77
Overhead back toss with a shot: 2.721kg	0.47	0.12 to 0.71
Underhand forward throw with a shot: 2.721kg	0.53	0.13 to 0.77

Table 3. Regression equations used to obtain the standard values.

	Regression equation	R^2	Standard Error
Grip strength: Right	y = 0.493x + 17.047	.18	6.29
Grip strength: Left	y = 0.4918x + 15.448	.21	5.73
Full squat	y = 2.6514x - 30.824	.47	17.09
Bench press	y = 1.4572x - 5.6001	.30	15.22
Snatch	y = 1.3308x - 15.53	.62	10.85
Clean	y = 1.8858x - 22.858	.58	23.37
Deadlift	y = 3.8522x - 75.901	.50	4.89
50m sprint	y = -0.0176x + 8.1934	.07	.42
Standing long jump	y = 1.1481x + 163.46	.15	17.41
Standing triple jump	y = 0.0491x + 3.9714	.34	.50
Standing quintuple jump	y = 0.0532x + 8.4244	.14	.88
Overhead back toss with a shot: 4.0kg	y = 0.1519x + 4.4813	.36	1.41
Underhand forward throw with a shot: 4.0kg	y = 0.1265x + 4.7917	.37	1.15
Overhead back toss with a shot: 2.721kg	y = 0.1794x + 4.7937	.20	1.73
Underhand forward throw with a shot: 2.721kg	y = 0.1595x + 5.0306	.24	1.43

Table 4. Standard values corresponding the throwing distance.

	Grip strength : Right	Grip strength : Left	Full squat	Bench press	Snatch	Clean	Deadlift	50m sprint	Standing long jump
30m	31.8	30.2	48.7	38.1	24.4	33.7	39.7	7.7	197.9
35m	34.3	32.7	62.0	45.4	31.0	43.1	58.9	7.6	203.6
40m	36.8	35.1	75.2	52.7	37.7	52.6	78.2	7.5	209.4
45m	39.2	37.6	88.5	60.0	44.4	62.0	97.4	7.4	215.1
50m	41.7	40.0	101.7	67.3	51.0	71.4	116.7	7.3	220.9
55m	44.2	42.5	115.0	74.5	57.7	80.9	136.0	7.2	226.6
60m	46.6	45.0	128.3	81.8	64.3	90.3	155.2	7.1	232.3
65m	49.1	47.4	141.5	89.1	71.0	99.7	174.5	7.0	238.1
70m	51.6	49.9	154.8	96.4	77.6	109.1	193.8	7.0	243.8
75m	54.0	52.3	168.0	103.7	84.3	118.6	213.0	6.9	249.6
80m	56.5	54.8	181.3	111.0	90.9	128.0	232.3	6.8	255.3

	Standing triple jump	Standing quintuple jump	Overhead back toss with a shot: 4.0kg	Underhand forward throw with a shot: 4.0kg	Overhead back toss with a shot: 2.721kg	Underhand forward throw with a shot: 2.721kg
30m	5.4	10.0	9.0	8.6	10.2	9.8
35m	5.7	10.3	9.8	9.2	11.1	10.6
40m	5.9	10.6	10.6	9.9	12.0	11.4
45m	6.2	10.8	11.3	10.5	12.9	12.2
50m	6.4	11.1	12.1	11.1	13.8	13.0
55m	6.7	11.4	12.8	11.7	14.7	13.8
60m	6.9	11.6	13.6	12.4	15.6	14.6
65m	7.2	11.9	14.4	13.0	16.5	15.4
70m	7.4	12.1	15.1	13.6	17.4	16.2
75m	7.7	12.4	15.9	14.3	18.2	17.0
80m	7.9	12.7	16.6	14.9	19.1	17.8

DISCUSSION

The aim of the study was to investigate the relationships between physical strength of female hammer throwers and their throwing performance and to create standard values corresponding to throwing distance. Our findings indicate that body weight was the only significant physique correlated with the throwing distance. The implement used in the hammer throw involves handle and wire, which may explain why height and arm span have less of an impact on throwing distance compared to other throwing events. In addition, as the high load applied to throwers in the hammer throw (Okamoto, 2007), it is necessary for hammer throwers to have higher power on the basis of greater muscle mass, and therefore body weight is important as the background. Additionally, Castaldi et al. (2022) refer to previous research and point out the importance of a large turning radius and the significant influence of body weight on it. Thus, the results of present study suggest that hammer throwers are required increasing muscle mass and gaining weight to improve their throwing performance.

In this study, the throwing distance in the hammer throw was significantly correlated with all physical strength variables, except for 30 m sprint. These findings emphasize the importance of developing both force and power to enhance hammer throwing performance, as strength and power are crucial for optimal performance in throwing events (Kline, 2003). Similar results have been obtained for other throwing events, such as the discus throw (male and female) and the javelin throw (male) (Hatakeyama et al., 2011; Maeda et al., 2018, 2019; Takanashi et al., 2021).

However, it is worth noting that while the 50 m sprint showed a significant correlation with the throwing distance in this study, the correlation coefficients of the sprinting variables were relatively smaller compared to other variables. Similar findings were observed in male discus throwers (Maeda et al., 2018). In contrast, for male javelin throwers, the correlation coefficient of the 100 m sprint was moderate (Maeda et al., 2019). The differences in the relationship between sprint variables and throwing distance can be attributed to the execution for throwing motion in limited space for hammer throwers and discus throwers, whereas javelin throwers are allowed to utilize an approach run.

In terms of the jumping variables, this study found moderate to large correlation coefficients with the throwing distance. Similar results were reported for the male discus and javelin throwers (Maeda et al., 2018, 2019). These results highlight the importance of jumping ability for throwers across different events. This suggests that coaches and throwers can measure and evaluate the ability to exert power in a short duration by focusing on training or testing the jumping variables.

Furthermore, in the discus and the javelin throws, previous studies have shown higher correlation coefficients of the throwing variables (overhead back toss with a shot and underhand forward throw with a shot) compared to the weight training variables to the throwing distance (Maeda et al., 2018, 2019). However, in the hammer throw, the results of this study revealed that the correlation coefficients of weight training variables were higher than those for the throwing variables. This can be attributed to the specific characteristics of the hammer throw, including longer duration time of motion (Hirose et al., 2016; Kato et al., 2020; Panoutsakopoulos and Kollias, 2012; Saratlija et al., 2013) and higher load applied to the thrower (Hirose et al., 2015; Lanka, 2000; Takamatsu and Sakurai, 2013) compared to other throwing events. In addition, the weight of the implements relative to throwers' body mass is heavier in the hammer throw compared to other throwing events, except for shot put. While the weight of the implement is the same in the shot put and hammer throw, the release velocity of the hammer is greater than that of the shot (elite female hammer throwers: over 26.0 m/s, elite female shot putters: around 13 m/s) (Dinsdale et al., 2018a, 2018b). This difference results in hammer throwers experience a higher load compared to shot putters, emphasizing the need for greater physical strength in the former. These factors likely contributed to the larger correlation coefficients observed for weight training variables in the hammer throw. Singh et al. (2013) revealed that high performance male hammer throwers demonstrated higher maximum strength compared to low performance throwers. Similarly, in this study, for female throwers, improving maximum strength through weight training was identified as a priority for enhancing the hammer throwing performance.

In this study, we estimated standard values corresponding to throwing distance using a single regression analysis. Typically, the throwing distance should serve as the dependent variable, while individual physical strength variables should be the independent variable. However, since one of the purposes of this study was to create standard values corresponding to throwing distance, we used a single regression equation with each variable as the dependent variable and the throwing distance as the independent variable. The coefficients of determination (R^2) ranged from .07 to .62, which is similar to the previous study that reported standard values for the strength of male javelin throwers (Maeda et al., 2019). Nonetheless, caution is warranted when applying estimated values of variables with small coefficients of determination and a limited sample size (e.g., 50 m sprint, standing triple jump, and 2.721 kg shot throw). We calculated the standard errors to evaluate the accuracy of the estimation and represent individual differences in throwers' physical strength. Therefore, when utilizing the standard values proposed in this study, coaches and athletes should consider the standard errors as a mean to evaluate the athletes' physical strength and set their goals. From a practical point of view, as noted by Bompa and Haff (2009), coaches can optimize athletes' performance by implementing a systematic and scientifically grounded training approach. Consequently, the standard values proposed in this study offer potential utility for coaches and athletes in identifying areas that require improvement in physical training, establishing goals, and designing scientifically informed training programs.

While we recruited a larger sample of participants than most previous studies, there still a number of limitations to the study's design. Firstly, the standard values were estimated for throwing distances ranging from 30 to 80 meters, however, the throwing distance of the participants only ranged from 30.31 to 63.82 meters. Therefore, the values from 65 to 80 meters were extrapolated, which could result in larger errors. Secondly, although the study was conducted with specific instructions to ensure consistent measurement, it's important to note that the use of a questionnaire-based approach inherently limits our ability to control the actual measurement environment. Lastly it should be noted that physical strength alone is not sufficient for enhancing the throwing performance in the hammer throw, as throwers also require good technique (Bandou et al., 2006). Physical strength and throwing technique are interrelated (Grosser and Neumaier, 1982). Future research should examine the relationship between physical strength and throwing technique in the hammer throw.

CONCLUSION

The purpose of this study was to clarify the relationships between female hammer throwers' physical strength and their throwing performance and to create standard values corresponding to throwing distance. A total of 82 female hammer throwers with throwing distances ranging from 30.31 to 63.82 meters participated in this study. Physical strength data were collected via a paper or online questionnaire. The results showed that all physical strength variables, except for 30 m sprint, were significantly correlated with the throwing distance, with weight training variables having the higher correlation coefficients. In addition, standard values corresponding to throwing distance were obtained using a single regression analysis, which can be useful for coaches and athletes.

AUTHOR CONTRIBUTIONS

Study concept and design, drafting the article and its critical revision: Kei Maeda. Data collection and analysis, final approval of the version to be published; Tadahiko Kato. Data analysis and interpretation, final approval of the version to be published; Jun Mizushima. Study concept and design, final approval of the version to be published: Mao Kuroda. Conception and design of the study, data collection and analysis, final approval of the version to be published; Keigo Ohyama-Byun.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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