

# Effects of standing and seated throws with varying implement weights on shot-put performance and shot velocity: Implications for training and adapted sports

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## Abstract

**Introduction.** In training practice, specific technical elements of the shot put are often isolated and practiced separately to refine technique and improve coordination. Based on this concept, minimizing lower-limb contribution by throwing from a standing or seated position allows athletes to focus more effectively on upper-body mechanics. Additionally, selecting lighter or heavier implements can be used to enhance explosive power or develop discipline-specific strength. **Aim of Study.** The present study investigated the effects of standing and seated throws with varying implement weights on shot-put performance, aiming to highlight potential training applications for shot putters. **Material and Methods.** Peak shot velocity (measured with a Doppler radar gun) and shot-put performance were assessed in 23 well-trained male and female collegiate students (age:  $21 \pm 1.7$  y; height: males  $173 \pm 7.4$  cm, females  $165 \pm 6.74$  cm; body mass: males  $76.4 \pm 5.6$  kg, females  $58.6 \pm 7.5$  kg) across six experimental conditions combining two throwing positions (seated, standing) with three implement weights (competition-standard, 25% lighter, 25% heavier). Anthropometric and physical performance parameters were evaluated. **Results.** The highest velocities were observed in standing throws with lighter or competition-weight shots, whereas heavy-shot throws produced lower velocities regardless of throwing position. Performance was strongly intercorrelated across all conditions, indicating consistent individual throwing capacity. Peak shot velocity was a significant predictor of performance, particularly in standing throws. Grip strength, lean body mass, lean throwing-arm mass, and height were positively associated with performance in both seated and standing conditions. **Conclusions.** Throwing position and implement weight distinctly modulate shot-put performance outcomes. Lighter implements are associated with velocity development and explosive performance, particularly in standing throws, whereas heavier implements emphasize force production and upper-body strength, regardless of throwing

position. These results support the strategic use of different shot weights and throwing positions as complementary training approaches to promote specific performance adaptations.

**KEYWORDS:** shot-put performance, shot velocity, seated shot put, power position, discipline-specific strength.

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## Introduction

Shot put, one of the two heavy throws in track and field along with the hammer throw, requires explosive leg power, upper-body and arm strength, and specific anthropometric characteristics [1-4]. The significance and contribution of these factors to throwing performance can vary depending on the technique adopted by the athlete. The rotational technique is often described in research as more explosive, whereas the glide technique is considered more dynamic [5, 6]. A common element of both techniques is that they culminate in the final position (power position), which aims to optimally place the body-implement system toward the throwing direction and create muscle pre-

activation that contributes to an efficient release of the shot. Correct execution of the power position is crucial for maximizing throwing performance, as the successive blocking actions (left leg, hip, left arm, and chest for a right-handed thrower) transfer the accumulated acceleration of the thrower-implement system to the shot, resulting in maximal shot velocity [7].

In training practice, key technical elements of the shot put are often isolated and practiced separately to refine technique, improve coordination, or develop the physical abilities required for effective performance [8]. This approach is frequently applied to the power position due to its critical role in throwing performance. Coaches intentionally minimize the contribution of leg activity during this phase by prescribing throws from a standing or seated position. This method allows athletes to fully concentrate on upper-body mechanics and encourages more dynamic movements.

For able-bodied athletes, the seated throw serves primarily as a training method, whereas for others it is a necessity. For instance, wheelchair throwers must perform the shot put from a throwing chair (throwing frame) as a natural and competitive requirement rather than a training variation. Additionally, the weight of the implement varies, depending on the athlete's classification, generally tending to lighter implements in accordance with the World Para Athletics Rules and Regulations (2024). Considering that technique and conditioning training in Paralympic shot put are limited to the upper body, it is imperative to explore how training methods used by able-bodied shot putters can be adapted to meet the specific demands of seated throwing.

Beyond traditional strength training with weightlifting and medicine-ball throws, many researchers emphasize the benefits of using implements of varying weight [9, 10], indicating that depending on the training goal, throwing with lighter or heavier implements can enhance explosive power and release velocity, build discipline-specific strength and refine technical components. Despite the established benefits of varying implement weights in standing throws, recent evidence regarding shot-put performance from a seated position across different implement weights is lacking [11]. Furthermore, the influence of anthropometric characteristics and physical performance parameters across diverse positions and implement weights remains unclear.

### Aim of Study

This study aims to investigate (i) the key aspects of standing and seated shot put using implements of

different weights, (ii) the physical and anthropometric factors affecting performance, (iii) the outcomes of combining throwing position and implement weights and their potential contributions to guiding training strategies for shot putters.

## Material and Methods

### Participants

The research sample comprised twenty-three ( $n = 23$ ) well-trained collegiate sport science students (mean age:  $21 \pm 1.7$  years), including nine males ( $n = 9$ ) (height:  $173 \pm 7.4$  cm; body mass:  $76.4 \pm 5.6$  kg) and fourteen females ( $n = 14$ ) (height:  $165 \pm 6.74$  cm; body mass:  $58.6 \pm 7.5$  kg). The participants were mainly track and field athletes ( $n = 18$ ), including seven ( $n = 7$ ) non-elite shot putters. Selection criteria required a satisfactory level of shot-put technique and the absence of any injuries. A written informed consent was obtained from all participants. The study was approved by the Ethics Committee of Approval No.: ΔΠΘ/EHΔΕ/67573/574, Ethics Committee of the Democritus University of Thrace, date of approval: 11/6/2025 and conducted in accordance with the Declaration of Helsinki.

### Testing procedures

Three days prior to the experimental procedure, specific anthropometric characteristics and physical performance parameters were evaluated, including: (i) standing and seated height (measured with a portable stadiometer, seca 213); (ii) arm span (measured with a rollfix tape, Hoechstmass); (iii) lean body mass and muscle mass of the throwing arm (assessed via Tanita MC-780MA-N); (iv) upper-extremity maximal pushing strength, with 1RM in bench-press performance determined using a standardized progressive protocol [12]; (v) lower-extremity power (assessed through three maximal countermovement jumps using OptoJump Next); and (vi) handgrip strength of the throwing hand (three maximal trials using a Takei 5401 Digital Hand Grip Dynamometer).

The evaluated parameters were selected based on the literature as factors influencing shot-put performance [13, 14]. Further tests, aside from the countermovement jump (CMJ), related to lower-extremity power and strength, such as the snatch and squat, were considered irrelevant for this study design, as the contribution of leg activity was minor in the context of the standing and seated shot-put throws. To ensure reliable relative measures of lean body mass, participants were instructed to undergo the

assessment in the morning, while well-rested, fasting, and adequately hydrated [15]. Additionally, they were advised to refrain from any training or intense physical activity for at least 24-48 hours prior to the experimental procedure.

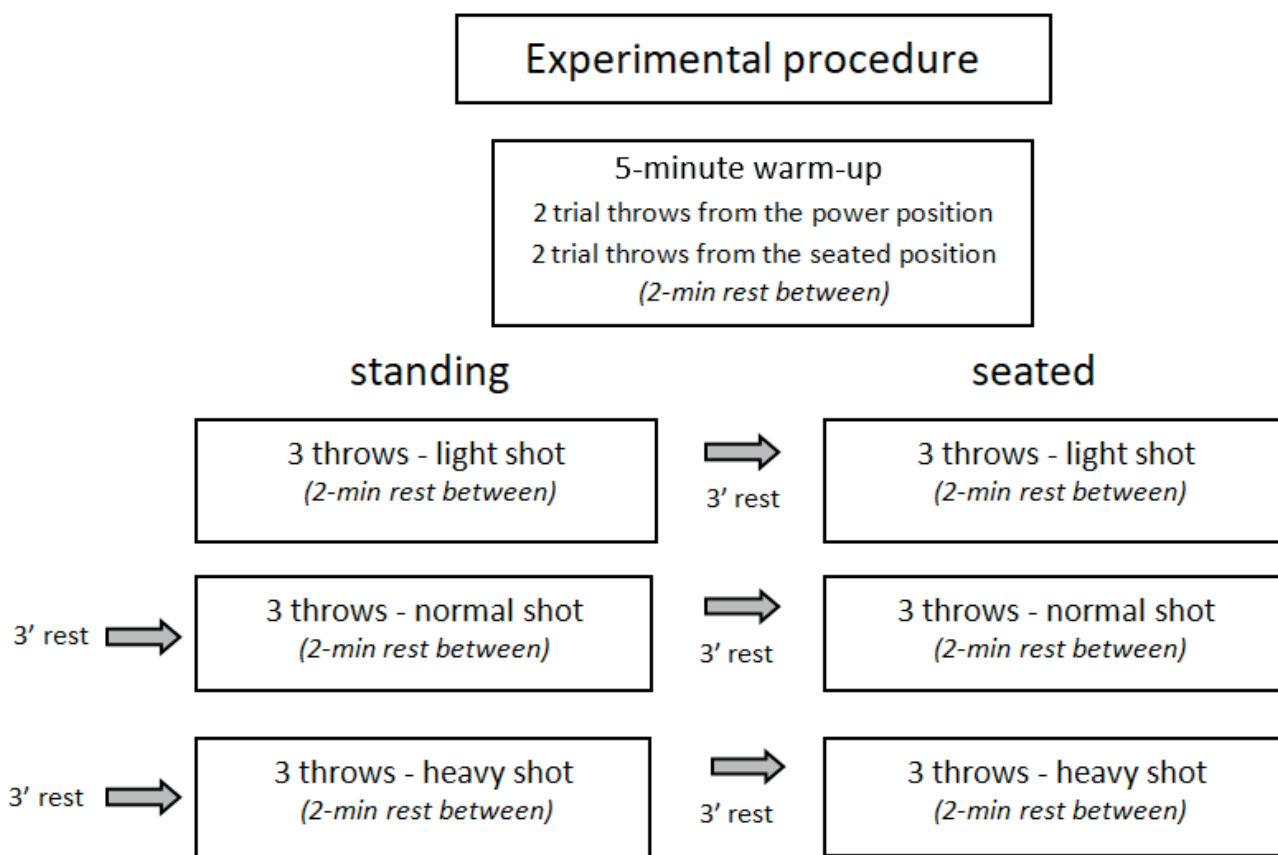
#### *Experimental procedure*

Each participant performed eighteen shot-put throws. Shot-put performance and maximal shot velocity were recorded under six different conditions: two throwing positions – (a) seated and (b) standing, and three implement weights – (a) a light shot, corresponding to a weight 25% lower than the competition-standard weight (3 kg for females and 5 kg for males); (b) a competition-standard shot (4 kg for females and 7.257 kg for males); and (c) a heavy shot, corresponding to a weight 25% higher than the competition-standard weight (6 kg for females and 9 kg for males). All throws were executed using the closest available IAAF-standardized shots. Three throws were performed for each condition, with a 2-minute rest interval between trials and a 3-minute rest between conditions. The sequence of experimental

conditions was randomized and counterbalanced across participants. Trials within each condition were performed in a randomized order with standardized rest intervals. Trial sequence information was not retained in the aggregated dataset used for analysis. Prior to testing, and to reduce the risk of injury, participants completed a 5-minute warm-up followed by two trial throws from each position (standing and seated), with a 2-minute rest between trials. The experimental design is presented in Figure 1.

#### *Shot-put performance measurement*

The standing throw was defined as the power position, initiated from a stationary stance with the torso and shoulder line rotated opposite to the throwing direction, the feet placed shoulder-width apart, and most of the body weight distributed over the slightly flexed rear leg. Seated throws were performed from the same stationary position but executed while seated on a wooden box with a height of 40 cm, which could be supplemented with an additional hard surface to ensure that the knee angle remained at 90° for all participants. Shot-put



**Figure 1.** Experimental design

performance for each participant was measured from the first mark of the shot to the start of a marked throwing line.

#### *Maximum (peak) shot-velocity measurement*

Maximum shot velocity was measured with a portable radar gun (Stalker ATS II Radar Gun). All radar measurements were taken from a fixed point, with the targeting height set approximately at 1.60 m for the seated position and 1.80 m for the standing position, ensuring consistent capture of the highest point of the shot's trajectory. The radar was activated just prior to the release of the projectile, and the shot's trajectory was continuously tracked throughout its flight to ensure accurate capture of peak velocity. Given that radar sensitivity decreases as the angle between the radar beam and the object's trajectory increases, the radar gun was positioned directly behind the thrower, aligning its line of sight with the direction of motion. This configuration effectively reduced the radar-trajectory angle to near zero, minimizing angular measurement error and eliminating the need for any post-measurement cosine correction. Velocity data were analyzed using the software provided with the radar system (Stalker II Software ATS 5.0).

#### *Statistical analysis*

All statistical analyses were conducted using the jamovi statistical software (version 2.7.17). Descriptive statistics for all variables included the mean (M) and standard deviation (SD). A power analysis was conducted using GPower 3.1. Collinearity among physical and anthropometric characteristics was assessed using preliminary Pearson correlation analyses. Lean throwing-arm mass was retained as the anthropometric covariate in the statistical models. Linear mixed-effects models, with subject as a random intercept and position and implements as main effects, as well as their interactions, were used to model peak shot velocity and shot-put performance. The Bonferroni-Holm correction was applied to eliminate inflation of the  $\alpha$  level in the post hoc tests, and all estimates are presented using 95% confidence intervals along with p-values. Regression models were assessed separately to evaluate the significance of changes between positions while adjusting for arm muscle mass. The significance level was set at 0.05 in all cases.

#### **Results**

The mean and standard deviation (SD) of the participants' physical and anthropometric characteristics are presented in Table 1, while Table 2 shows the mean

and SD of shot-put performance and the corresponding peak shot velocity for each throwing position and shot weight by gender.

**Table1.** Physical and anthropometric characteristics of athletes

|                      | Gender |      |        |       |
|----------------------|--------|------|--------|-------|
|                      | Female |      | Male   |       |
|                      | Mean   | SD   | Mean   | SD    |
| chest press (kg)     | 30.68  | 4.71 | 76.56  | 20.12 |
| grip test (kg)       | 30.26  | 3.59 | 48.96  | 10.92 |
| CMJ test (cm)        | 28.08  | 5.15 | 43.50  | 7.33  |
| arm muscle mass (kg) | 2.07   | .41  | 3.86   | 1.13  |
| lean body mass (kg)  | 43.51  | 4.57 | 60.38  | 9.35  |
| height (cm)          | 164.82 | 6.74 | 172.72 | 7.36  |
| sitting height (cm)  | 88.01  | 3.28 | 92.50  | 3.35  |
| arm span (cm)        | 169.31 | 9.69 | 176.00 | 11.46 |

Note: CMJ – countermovement jump; SD – standard deviation.

As shown in Figure 2a for the female participants, shot-put performance appeared to be influenced by both the throwing position and the weight of the implement. The conditional model's  $R^2$  was 0.932, and the marginal  $R^2$  was 0.887. The AIC of the model was 153.3, and the BIC was 175.2. A statistically significant effect was detected for the factor "Position" ( $F_{1,65} = 799.23$ ,  $p < 0.001$ ), for "Weight" ( $F_{2,65} = 103.70$ ,  $p < 0.001$ ), and for their interaction ( $F_{2,65} = 5.45$ ,  $p = 0.006$ ). Arm muscle mass was also positively correlated with shot-put performance ( $\beta = 1,003$ , 95% CI:0.4375 – 1.568,  $p = 0.004$ ). Post hoc tests indicated statistically significant differences across all weights within each position and between the two positions across all weights (Table 3). The highest performance was recorded with the light shot ( $7.52 \pm 0.84$  m), which also showed the greatest difference between the standing and seated throws ( $3.22 \pm 0.78$  m). For the competition-weight shot, this difference was slightly smaller ( $2.81 \pm 0.76$  m), whereas the heaviest shot showed the smallest performance difference between the two positions ( $2.41 \pm 0.74$  m), suggesting that heavier shots are less influenced by throwing position compared with lighter shots ( $p = 0.008$ ).

Similar findings were observed for the male participants, where shot-put performance appeared to be influenced

**Table 2.** Comparison of shot-put performance and peak shot velocity across all experimental conditions by gender

| (a)      |                       | Females                  |      |                            |      |
|----------|-----------------------|--------------------------|------|----------------------------|------|
|          |                       | Shot-put performance (m) |      | Peak shot velocity (m/sec) |      |
|          |                       | Mean                     | SD   | Mean                       | SD   |
| standing | light implement       | 7.52                     | 0.84 | 6.90                       | 0.62 |
|          | competition implement | 6.52                     | 0.82 | 6.42                       | 0.52 |
|          | heavy implement       | 5.37                     | 0.77 | 5.61                       | 0.66 |
| seated   | light implement       | 4.31                     | 0.72 | 5.45                       | 0.52 |
|          | competition implement | 3.70                     | 0.52 | 5.17                       | 0.43 |
|          | heavy implement       | 2.96                     | 0.49 | 4.71                       | 0.52 |
| (b)      |                       | Males                    |      |                            |      |
|          |                       | Shot-put performance (m) |      | Peak shot velocity (m/sec) |      |
|          |                       | Mean                     | SD   | Mean                       | SD   |
| standing | light implement       | 9.81                     | 2.10 | 7.61                       | 0.76 |
|          | competition implement | 8.20                     | 1.61 | 6.88                       | 0.54 |
|          | heavy implement       | 7.45                     | 1.42 | 6.60                       | 0.66 |
| seated   | light implement       | 5.85                     | 1.74 | 6.24                       | 0.64 |
|          | competition implement | 4.54                     | 1.12 | 5.33                       | 0.58 |
|          | heavy implement       | 4.07                     | 0.96 | 5.12                       | 0.56 |

Note: light implement – 3-kg shot for females and 5-kg for males; competition implement – 4-kg shot for females and 7.26-kg for males; heavy implement– 6-kg shot for females and 9-kg for males; SD – standard deviation.

**Table 3.** Post hoc comparisons for female shot-put performance

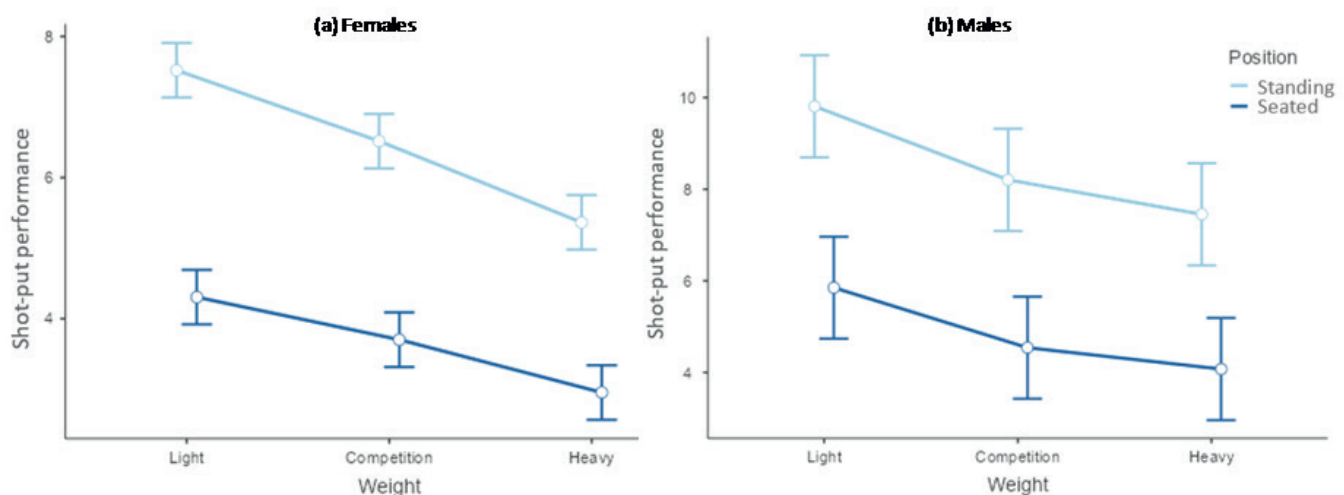
| Comparison |             |     |          |             |            |       |       |      |                   |
|------------|-------------|-----|----------|-------------|------------|-------|-------|------|-------------------|
| Position   | Weight      | vs. | Position | Weight      | Difference | SE    | t     | df   | p <sub>holm</sub> |
| standing   | light       | -   | standing | competition | 1.004      | 0.172 | 5.82  | 65.0 | <0.001            |
| standing   | light       | -   | standing | heavy       | 2.155      | 0.172 | 12.51 | 65.0 | <0.001            |
| standing   | light       | -   | seated   | light       | 3.215      | 0.172 | 18.65 | 65.0 | <0.001            |
| standing   | light       | -   | seated   | competition | 3.818      | 0.172 | 22.15 | 65.0 | <0.001            |
| standing   | light       | -   | seated   | heavy       | 4.566      | 0.172 | 26.49 | 65.0 | <0.001            |
| standing   | competition | -   | standing | heavy       | 1.152      | 0.172 | 6.68  | 65.0 | <0.001            |
| standing   | competition | -   | seated   | light       | 2.212      | 0.172 | 12.83 | 65.0 | <0.001            |
| standing   | competition | -   | seated   | competition | 2.814      | 0.172 | 16.33 | 65.0 | <0.001            |
| standing   | competition | -   | seated   | heavy       | 3.562      | 0.172 | 20.67 | 65.0 | <0.001            |
| standing   | heavy       | -   | seated   | light       | 1.060      | 0.172 | 6.15  | 65.0 | <0.001            |
| standing   | heavy       | -   | seated   | competition | 1.662      | 0.172 | 9.64  | 65.0 | <0.001            |
| standing   | heavy       | -   | seated   | heavy       | 2.410      | 0.172 | 13.99 | 65.0 | <0.001            |
| seated     | light       | -   | seated   | competition | 0.602      | 0.172 | 3.49  | 65.0 | <0.001            |
| seated     | light       | -   | seated   | heavy       | 1.351      | 0.172 | 7.84  | 65.0 | <0.001            |
| seated     | competition | -   | seated   | heavy       | 0.748      | 0.172 | 4.34  | 65.0 | <0.001            |

by both the throwing position and the weight of the implement. The conditional model's  $R^2$  was 0.911, and the marginal  $R^2$  0.870. The AIC of the model was 152.0 and the BIC was 169.9. A statistically significant effect was detected for the factor "Position" ( $F_{1,40} = 314.695$ ,  $p < 0.001$ ) and for "Weight" ( $F_{2,40} = 35.219$ ,  $p < 0.001$ ),

but not for their interaction ( $F_{2,40} = 0.660$ ,  $p = 0.522$ ). Arm muscle mass was also positively correlated with shot-put performance ( $\beta = 1.114$ , 95% CI: 0.736 – 1.493,  $p < 0.001$ ). Post hoc tests indicated statistically significant differences across all weights in the two positions, except for the comparison between the competition-

**Table 4.** Post hoc comparisons for male shot-put performance

| Comparison |             |     |          |             | Difference | SE    | t     | df   | $p_{\text{holm}}$ |
|------------|-------------|-----|----------|-------------|------------|-------|-------|------|-------------------|
| Position   | Weight      | vs. | Position | Weight      |            |       |       |      |                   |
| standing   | light       | -   | standing | competition | 1.605      | 0.358 | 4.48  | 40.0 | <0.001            |
| standing   | light       | -   | standing | heavy       | 2.358      | 0.358 | 6.59  | 40.0 | <0.001            |
| standing   | light       | -   | seated   | light       | 3.958      | 0.358 | 11.06 | 40.0 | <0.001            |
| standing   | light       | -   | seated   | competition | 5.268      | 0.358 | 14.72 | 40.0 | <0.001            |
| standing   | light       | -   | seated   | heavy       | 5.734      | 0.358 | 16.02 | 40.0 | <0.001            |
| standing   | competition | -   | standing | heavy       | 0.753      | 0.358 | 2.10  | 40.0 | 0.083             |
| standing   | competition | -   | seated   | light       | 2.353      | 0.358 | 6.57  | 40.0 | <0.001            |
| standing   | competition | -   | seated   | competition | 3.663      | 0.358 | 10.23 | 40.0 | <0.001            |
| standing   | competition | -   | seated   | heavy       | 4.130      | 0.358 | 11.54 | 40.0 | <0.001            |
| standing   | heavy       | -   | seated   | light       | 1.600      | 0.358 | 4.47  | 40.0 | <0.001            |
| standing   | heavy       | -   | seated   | competition | 2.910      | 0.358 | 8.13  | 40.0 | <0.001            |
| standing   | heavy       | -   | seated   | heavy       | 3.377      | 0.358 | 9.43  | 40.0 | <0.001            |
| seated     | light       | -   | seated   | competition | 1.310      | 0.358 | 3.66  | 40.0 | 0.002             |
| seated     | light       | -   | seated   | heavy       | 1.776      | 0.358 | 4.96  | 40.0 | <0.001            |
| seated     | competition | -   | seated   | heavy       | 0.467      | 0.358 | 1.30  | 40.0 | 0.200             |



**Figure 2.** Shot put performance across throwing positions and implement weights

weight and heavy shots in either group, which may be attributed to the low sample size of male participants. Differences between the two positions across all weights were also statistically significant (Table 4, Figure 2b).

The highest performance was recorded with the light shot ( $9.81 \pm 2.10$  m), which also showed the greatest difference between the standing and seated throws ( $3.96 \pm 1.65$  m). For the competition-weight shot, this difference was slightly smaller ( $3.66 \pm 1.08$  m), whereas the heaviest shot showed the smallest performance difference between the two positions ( $3.38 \pm 0.85$  m). Nevertheless, the differences recorded in male participants were not statistically significant. Maximum (peak) shot velocity was also influenced by the throwing position and the implement weight (Figures 3a and 3b). For the female participants, the conditional model's  $R^2$  was 0.878 and the marginal  $R^2$  was 0.712. The AIC of the model was 108.3 and the BIC was 130.2. A statistically significant effect was detected for the factor "Position" ( $F_{1,65} = 284.19, p < 0.001$ ), for "Weight" ( $F_{2,65} = 69.95, p < 0.001$ ), and for their interaction ( $F_{2,65} = 5.06, p = 0.009$ ). Arm muscle mass was also positively correlated with shot velocity ( $\beta = 0.648, 95\% \text{ CI}: 0.102$

$- 1.194, p = 0.036$ ). Post hoc tests indicated statistically significant differences across all weights within each position and between the two positions across all weights (Table 5).

For the light and competition-weight shots, the differences in peak velocity between the standing and seated positions were slightly larger (light shot:  $1.45 \pm 0.43$  m/s; competition shot:  $1.24 \pm 0.42$  m/s). In contrast, peak velocities with the heavy shot were substantially lower ( $0.91 \pm 0.56$  m/s) compared with the light shot ( $p = 0.004$ ).

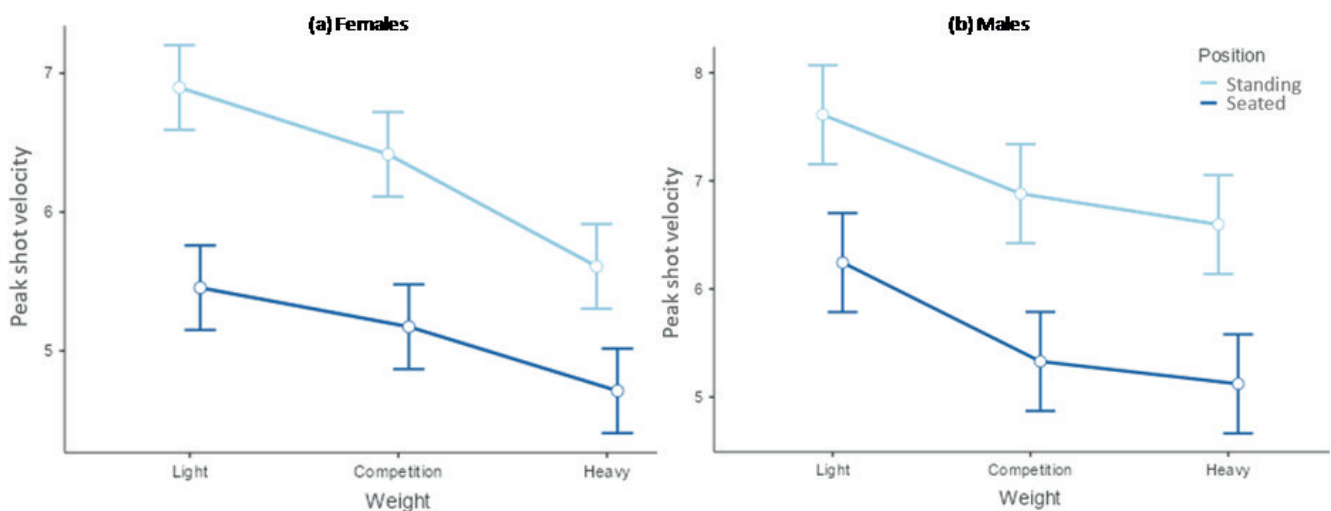
For the male participants, the conditional model's  $R^2$  was 0.925 and the marginal  $R^2$  was 0.832. The AIC of the model was 68.3 and the BIC was 86.2. A statistically significant effect was detected for the factor "Position" ( $F_{1,65} = 337.05, p < 0.001$ ), for "Weight" ( $F_{2,65} = 65.627, p < 0.001$ ), but not for their interaction ( $F_{2,65} = 0.453, p = 0.639$ ). Arm muscle mass was also positively correlated with shot velocity ( $\beta = 0.414, 95\% \text{ CI}: 0.194 - 1.635, p = 0.007$ ). Post hoc tests indicated statistically significant differences across all weights within each position, except for the comparison between the competition-weight and heavy shots in either group. Differences between the two positions across all weights were also statistically significant (Table 6, Figure 3b).

**Table 5.** Post hoc comparisons for female peak shot-put velocity

| Comparison |             |     |          |             | Difference | SE    | t     | df   | $P_{\text{holm}}$ |
|------------|-------------|-----|----------|-------------|------------|-------|-------|------|-------------------|
| Position   | Weight      | vs. | Position | Weight      |            |       |       |      |                   |
| standing   | light       | -   | standing | competition | 0.481      | 0.123 | 3.92  | 65.0 | 0.001             |
| standing   | light       | -   | standing | heavy       | 1.289      | 0.123 | 10.50 | 65.0 | <0.001            |
| standing   | light       | -   | seated   | light       | 1.443      | 0.123 | 11.76 | 65.0 | <0.001            |
| standing   | light       | -   | seated   | competition | 1.724      | 0.123 | 14.05 | 65.0 | <0.001            |
| standing   | light       | -   | seated   | heavy       | 2.186      | 0.123 | 17.81 | 65.0 | <0.001            |
| standing   | competition | -   | standing | heavy       | 0.808      | 0.123 | 6.58  | 65.0 | <0.001            |
| standing   | competition | -   | seated   | light       | 0.962      | 0.123 | 7.84  | 65.0 | <0.001            |
| standing   | competition | -   | seated   | competition | 1.243      | 0.123 | 10.13 | 65.0 | <0.001            |
| standing   | competition | -   | seated   | heavy       | 1.705      | 0.123 | 13.89 | 65.0 | <0.001            |
| standing   | heavy       | -   | seated   | light       | 0.154      | 0.123 | 1.26  | 65.0 | 0.213             |
| standing   | heavy       | -   | seated   | competition | 0.435      | 0.123 | 3.55  | 65.0 | 0.002             |
| standing   | heavy       | -   | seated   | heavy       | 0.897      | 0.123 | 7.31  | 65.0 | <0.001            |
| seated     | light       | -   | seated   | competition | 0.281      | 0.123 | 2.29  | 65.0 | 0.051             |
| seated     | light       | -   | seated   | heavy       | 0.743      | 0.123 | 6.05  | 65.0 | <0.001            |
| seated     | competition | -   | seated   | heavy       | 0.462      | 0.123 | 3.76  | 65.0 | 0.001             |

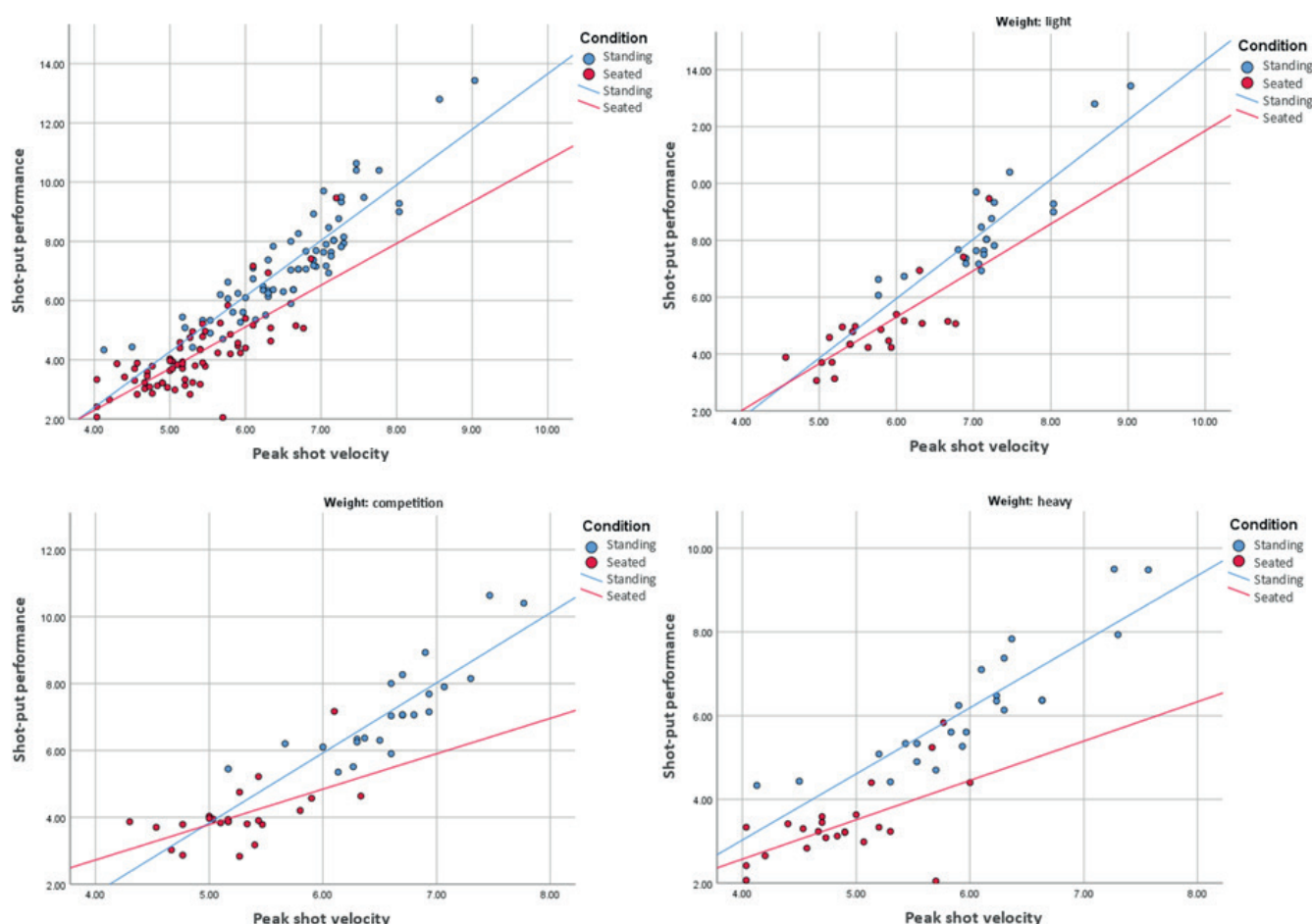
**Table 6.** Post hoc comparisons for male peak shot-put velocity

| Comparison |             |     |          |             | Difference | SE    | t     | df   | P <sub>holm</sub> |
|------------|-------------|-----|----------|-------------|------------|-------|-------|------|-------------------|
| Position   | Weight      | vs. | Position | Weight      |            |       |       |      |                   |
| standing   | light       | -   | standing | competition | 0.730      | 0.138 | 5.28  | 40.0 | <0.001            |
| standing   | light       | -   | standing | heavy       | 1.015      | 0.138 | 7.35  | 40.0 | <0.001            |
| standing   | light       | -   | seated   | light       | 1.367      | 0.138 | 9.89  | 40.0 | <0.001            |
| standing   | light       | -   | seated   | competition | 2.281      | 0.138 | 16.52 | 40.0 | <0.001            |
| standing   | light       | -   | seated   | heavy       | 2.489      | 0.138 | 18.02 | 40.0 | <0.001            |
| standing   | competition | -   | standing | heavy       | 0.285      | 0.138 | 2.06  | 40.0 | 0.091             |
| standing   | competition | -   | seated   | light       | 0.637      | 0.138 | 4.61  | 40.0 | <0.001            |
| standing   | competition | -   | seated   | competition | 1.552      | 0.138 | 11.23 | 40.0 | <0.001            |
| standing   | competition | -   | seated   | heavy       | 1.759      | 0.138 | 12.74 | 40.0 | <0.001            |
| standing   | heavy       | -   | seated   | light       | 0.352      | 0.138 | 2.55  | 40.0 | 0.044             |
| standing   | heavy       | -   | seated   | competition | 1.267      | 0.138 | 9.17  | 40.0 | <0.001            |
| standing   | heavy       | -   | seated   | heavy       | 1.474      | 0.138 | 10.67 | 40.0 | <0.001            |
| seated     | light       | -   | seated   | competition | 0.915      | 0.138 | 6.62  | 40.0 | <0.001            |
| seated     | light       | -   | seated   | heavy       | 1.122      | 0.138 | 8.12  | 40.0 | <0.001            |
| seated     | competition | -   | seated   | heavy       | 0.207      | 0.138 | 1.50  | 40.0 | 0.141             |

**Figure 3.** Shot peak velocity across throwing positions and implement weights

The results for the male participants showed no significant changes in peak velocity across weights. Similar differences were observed between the two positions for the light shot ( $1.38 \pm 0.40$  m/s), the competition-weight shot ( $1.56 \pm 0.42$  m/s) and the heavy shot ( $1.48 \pm 0.50$  m/s). To evaluate the effect size of maximum shot velocity on shot-put performance, a linear mixed model

was applied. The aim was to assess the potential of predicting shot-put performance based on maximum shot velocity. The results, standardized for all anthropometric measurements due to the statistically significant preliminary findings, indicated that peak shot velocity had a statistically significant effect on shot-put performance ( $\beta = 0.735$ , 95% CI: 0.502 –



**Figure 4.** Effect size of peak shot velocity on shot put performance

0.967,  $p < 0.001$ ). Its interaction with throwing position was also statistically significant, with higher predictive value in standing versus seated throws ( $\beta = 0.484$ , 95% CI: 0.247 – 0.721,  $p < 0.001$ ). These findings suggest that maximum shot velocity is a significant predictor of shot-put performance, particularly under standing throw conditions. However, its predictive value appears attenuated in seated conditions, as illustrated in the corresponding scatter plots (Figure 4). The interaction of peak shot velocity was not statistically significant ( $p = 0.200$ ). Similar results were observed for grip strength, where its interaction with implement weight was statistically significant for the comparisons light vs. competition ( $\beta = 0.022$ , 95% CI: 0.005 – 0.039,  $p = 0.012$ ) and light vs. heavy ( $\beta = 0.023$ , 95% CI: 0.006 – 0.040,  $p = 0.007$ ). Among the remaining anthropometric characteristics, statistically significant effects were also found for height ( $\beta = -0.044$ , 95% CI: -0.071 – -0.018,  $p < 0.001$ ) and lean body mass ( $\beta = 0.099$ , 95% CI: -0.065 – 0.134,  $p < 0.001$ ).

## Discussion

This study aimed to explore key aspects of standing and seated shot-put performance using implements of different weights, with the goal of determining how combinations of throwing position and implement weight can inform training strategies for shot-putters. The main finding was that various combinations of shot weights and throwing positions (standing or seated) influenced maximum shot velocity and the overall dynamic of the throw in distinct ways.

### *Combination of throwing position and shot weight*

The difference in peak shot velocity between the standing and seated throws was slightly larger for the light shot compared with the competition-weight shot, although the overall magnitude of the difference remained small. This outcome can be attributed to the similar level of explosive contribution from the involved muscle groups when throwing with lighter shots. Supporting this finding, research by Dinu, Houel, & Louis [9] has

shown that when the weight difference of the throwing implement is minimal, the biomechanical parameters of the throw, and consequently the technique performance, are not significantly affected. In contrast, heavy shot throws resulted in significantly lower velocities, due to the requirement for greater force application and the slower shot acceleration with only minor differences between the two positions. Furthermore, the linear regression analysis indicated that the predictive value of peak shot velocity on performance was lower in all seated throws, suggesting that seated shot-put performance is influenced by additional factors such as upper-body strength and anthropometric characteristics. These insights can be translated into shot-put training strategies by varying both the implement weight and the throwing position. When the goal is to develop explosiveness and maximize throwing speed, lighter implements should be prioritized regardless of the throwing position. Conversely, when the focus is on enhancing the specific strength of the upper-body muscles involved in throwing, heavier implements should be chosen - particularly in the seated position, which places greater emphasis on the engagement of these muscle groups. Moreover, heavier implements slow down the throwing motion, allowing for more precise sequencing of muscle activation during execution.

These considerations may also be relevant for wheelchair shot-putters, as developing upper-body explosiveness and strength in the seated position is a primary goal for coaches. However, the present findings are based on able-bodied collegiate athletes, and differences in neuromuscular constraints, classification, and throwing conditions should be taken into account when considering their applicability to wheelchair athletes. In this context, the findings may serve as a reference point for future research examining seated shot-put performance in wheelchair throwers. Nevertheless, a previous study of Chow and Mindock [16] demonstrated that hand speed is a crucial factor in seated throwing performance, which led to the establishment of the seated force throw as a key performance indicator, particularly in the absence of lower-limb contribution. Similarly, release speed in Paralympic seated shot put was identified by Lee et al. [17] as a significant predictor of performance ( $r = 0.95$ ,  $p < 0.01$ ), explaining approximately 89-96% of the variance in distance thrown.

#### *Grip strength, pushing strength, and lower-extremity power*

The most significant physical parameter related to shot-put performance was grip strength, which is recognized as essential for the stable handling and control of the

throwing implement. This supports a direct relationship between grip strength and overall upper-body strength, as suggested by other research [18, 19].

Although pushing strength was not included in the main predictive model, preliminary Pearson correlation analyses revealed a positive association with shot-put performance, suggesting that upper-body pushing capacity may contribute to throwing outcomes. This observation aligns with previous research highlighting the importance of upper-body strength in shot put, but it should be interpreted with caution given that it is based on exploratory analyses. Further research indicates that performance in bench press exercises, whether performed in a supine position [1, 12, 20] or standing [21], is a key predictor of competitive shot-put performance, particularly among seated Para throwers [22]. Studies suggest that seated throws require more intense activation of the upper-body muscle groups, mainly the throwing arm, compared to standing throws, due to the absence of active leg contribution in accelerating the shot [23, 24]. Accordingly, exercises that simulate the dynamics of the throwing motion and specifically strengthen the muscle groups activated during the shot-put kinetic sequence should be prioritized in training programs [25].

Lower-extremity power, as assessed via the (CMJ), did not show a strong effect on shot-put performance. This finding stands in contrast to previous studies that have highlighted lower-limb muscular power as a key factor in shot-put performance [2, 26], with some even identifying it as the best predictor of throwing success [27]. However, the lack of association between lower-limb power and throwing distance in the present study is entirely expected, given that leg involvement was negligible in the seated throw and limited to a minor push during the final phase of the standing throw.

#### *Anthropometric characteristics*

Among anthropometric characteristics, lean body mass and throwing-arm muscle mass were associated with higher shot-put performance, with the latter showing a strong correlation across all conditions. Previous studies linking throwing performance to anthropometric factors have demonstrated that lean body mass [2, 4], especially in the throwing arm [28], is crucial for enhancing movement speed and release velocity, as it is highly associated with strength [1]. Consequently, coaches and shot-put athletes should focus on increasing muscle mass and minimizing body fat through targeted training and nutrition strategies as a supplementary approach to improving performance.

Significant effects on performance were also observed for the factor “Height”, consistent with previous research suggesting that elite throwers generally benefit from greater stature to optimize release height [12, 28]. In contrast, arm span demonstrated a weaker association with shot-put performance. This finding contradicts evidence showing that arm span has been identified as a critical factor for achieving high performance in throws, as it provides a longer lever arm that allows the generated force to be applied over a greater distance and for a longer duration. Similar conclusions have also been reported in studies on seated athletes [24, 29]. The moderate effect observed in the present study may be explained by the biomechanical characteristics of shot put, which are more pronounced in seated throws. In this context, maximizing the trajectory over which force is applied to the implement is not achieved by stretching the arm back—as in other throwing events—but rather by rotating the torso away from the shot-release point. This also explains why “Height” was the only anthropometric parameter that appeared to influence shot-put performance, as it reflects the length of the upper torso. In this context, in Paralympic seated shot put—where the torso muscles cannot support a backward movement—athletes are allowed to brace against a stable assistive pole to enhance the backward lean [30].

#### *Limitations and directions for further research*

The present findings contribute to the understanding of shot-put performance; however, several methodological limitations should be acknowledged. These include the relatively small sample size, the inclusion of both male and female participants despite sex-specific implement weights, and heterogeneity in participants’ training status. A further limitation was that, despite randomization of condition order, the absence of retained trial-sequence data precluded a formal assessment of potential order or fatigue effects.

Future research should include sex-stratified analyses and larger, more homogeneous samples, and incorporate measures of muscle activity (e.g., electromyography) to further examine neuromuscular contributions during throws performed from different positions and with varying implement weights.

#### **Conclusions**

In conclusion, heavy shot throws result in significantly lower velocities, regardless of throwing position, demanding greater force application and upper-body strength. In contrast, higher shot velocities are achieved with lighter or competition-weight shots, engaging

greater explosiveness and controlled muscle activation, especially in standing throws. Grip strength and lean muscle mass—particularly in the throwing arm—as key predictors of performance in both seated and standing positions should be prioritized in training. These findings provide practical guidance for designing shot-put training, suggesting the strategic use of different shot weights and throwing positions to target either explosiveness or upper-body strength. Furthermore, they offer a reference point for future research in seated Paralympic athletes, though caution is warranted due to differing neuromuscular constraints, classification systems, and throwing conditions.

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#### **Conflict of Interest**

The authors declare no conflict of interest.

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