ORIGINAL ARTICLE

Comparison of snatch performance and barbell trajectory in elite weightlifters according to bodyweight categories

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ABSTRACT

This study was to compare the kinetic and kinematic differences in the snatch performances and barbell trajectory of the elite weightlifters. Two synchronized cameras recorded successful snatch performances during the 2010 World Weightlifting Championships. Weightlifters were separated into three bodyweight categories (BWCs) light weight (LWC), middle weight (MWC), and heavy weight (HWC). All performances were analysed using the Ariel Performance Analysis System. The Kolmogorov-Smirnov test was used for normality. A one-way ANOVA and Bonferroni correction post hoc test were used to determine group and subgroup differences. Relative barbell mass significantly decreased as the BWCs increased. Lower extremity angular movements showed similar performance outcomes in BWCs. As the BWCs increased, the barbell heights at the end of the first and second pulls significantly increased, and similarly, the maximum barbell height increased. There were no statistically significant differences in the horizontal movement of the barbell in all BWCs. In addition, the LWC lifted more heavy relative barbell mass than other WCs. Besides, HWC performed less relative power than others in the second pull. Consequently, lower barbell height and higher power output during the second pull might be clues for successfully lifting higher weights in the snatch technique.
Keywords: Performance analysis, Weightlifting, Snatch, Mechanical work, Power, Biomechanics.

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INTRODUCTION

Weightlifting is an Olympic sport that includes two main categories: the snatch and the clean and jerk, which utilise the entire body power. However, the strength of lower extremity plays a crucial role in lifting the barbell during the performance, especially snatch. Mastering the snatch lift requires both physical strength and a comprehensive understanding of kinematics, kinetics, and timing, making it one of the most technically demanding athletic skills (Arauz et al., 2025). Also, technique differences affect snatch performance (Arauz et al., 2024).

The Double Knee Bend (DKB) is used by weightlifters throughout the snatch performance (Baumann et al., 1988). DKB involves an extension-flexion-extension sequence and allows athletes to effectively use their legs to regulate and control movements. The kinematics of the DKB in the snatch are examined in five phases: as first pull, transition, the second pull, the turnover under the barbell and the catch phase (Baumann et al., 1988; Gourgoulis et al., 2000; Gourgoulis et al., 2002; Hakkinen et al., 1984; Zahran et al., 2025). The kinetic and kinematic patterns between these phases may change. Therefore, the determination of kinetic and kinematic differences between the phases may help to explain elite or successful performance.

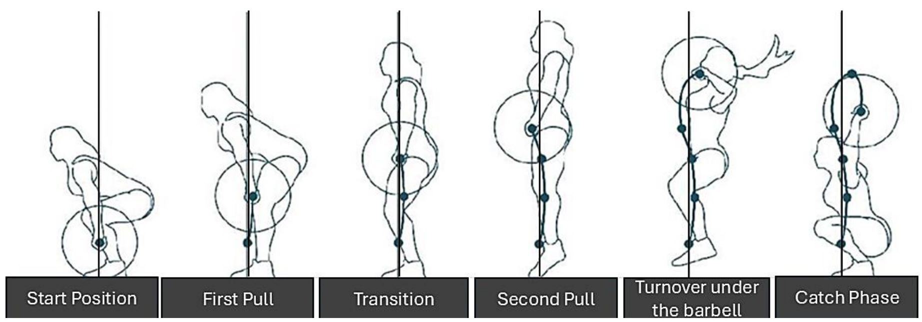


Figure 1. Phases of snatch (revised from study from Zahran et al. (2025))

The pull (from the start position to waist height) is the initial position of the snatch by lower extremity musculature (Arauz et al., 2024; Enoka, 1979, 1988; Geisler et al., 2023; Zahran et al., 2025). In addition to successfully performing, athletes need to have high muscular power and skill level in the snatch technique (Stone et al., 1998). Indeed, the snatch technique is related to the barbell kinematics and the athletes' kinematics and kinetics. The kinematic pattern of the total pull that is composed of the first pull, transition and second pull influences the success of the subsequent phases, including the turnover under the barbell and the catch phase (Baumann et al., 1988; Gourgoulis et al., 2000).

The technical skill is one of the most important factors in performance (Arauz et al., 2025; Liu et al., 2018). Because the technique used during the lift influences the trajectory of the barbell and its linear kinematics, resulting from the coordinated movement of the body and its segments, such as the angular kinematics of the lower limb (Baumann et al., 1988; Burdett, 1982; Gourgoulis et al., 2000), the trajectory of the barbell (Garhammer, 1982; Hoover et al., 2006; Schilling et al., 2002; Vorobyev, 1978; Whitehead et al., 2014) and the other mechanical factors (Arauz et al., 2024; Enoka, 1979; Garhammer, 1980; Gourgoulis et al., 2002). Moreover, power production of the athletes may be affected by small variations in the technique. And it can lead to an effect on the performance in the snatch.

The power production that depends on the body mass of athletes is limited (Garhammer, 1980; Lee et al., 2018). Therefore, the weightlifters race in different weight class. In addition, as the weight class increases, the kinetic and kinematics parameters during the snatch performance may affect due to the increased weight of the barbell (Ho et al., 2014). Therefore, the present study was to compare the kinetic and kinematic differences of the lower extremity and barbell trajectories between the snatch performances of elite weightlifters.

METHODS

Participants

The 52 male weightlifters who placed in the final groups during the 2010 World Weightlifting Championship (78th Men's and 21st Women's World Championships in Antalya, Türkiye) in the study. All participants signed an informed consent form to the Declaration of Helsinki. The weightlifters were separated 6 BWCs (56, 62, 77, 85, 94, and 105-kg). The categories were classified as light (56 and 62-kg, LC), middle (77 and 85-kg, MC), and heavy bodyweight category (94 and 105-kg HC)). The study was approved by the local ethics committee of the Faculty of Sport Sciences of the Selçuk University (Date and approval number: 28/01/2022, 22).

Experimental setup and data collection

All weightlifters performed the snatch lift on a platform. All successful performances of the weightlifters were recorded on an SD card in Audio Video Interleave (AVI) data type by two digital cameras (Sony DCR-TRV18E, Tokyo, Japan) at 50 Hz. The cameras were placed perpendicular to where diagonal of the movement area on the platform, as shown in Figure 2. A rectangular cube (length: 250 cm, depth: 100 cm, height: 180 cm) was used for calibration of the movement space on the platform.

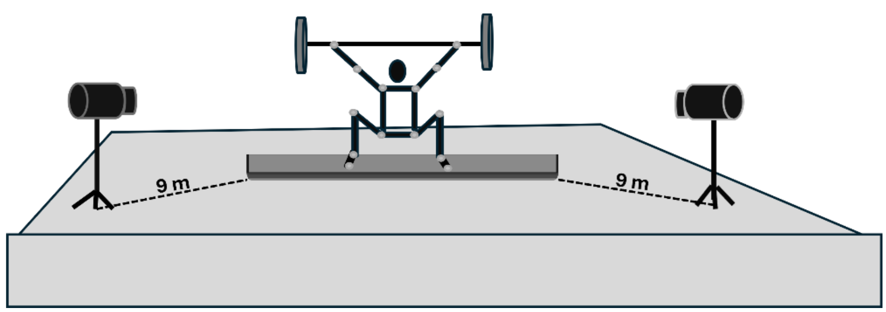


Figure 2. Experimental setup.

Data processing

The videos were transformed from AVI to JPG data type, being lossless. The Ariel Performance Analysis System (APAS, San Diego, USA) was used for digitization of each image. To synchronize the images obtained from two video cameras, the initial motion moment of the barbell from the ground was used for all performances. A point on the medial side of the right hand was determined to detect barbell trajectory. Five points on the right side of the body were digitized (5th metatarsal joint for the toe, the lateral malleolus for the ankle, the lateral epicondyle for the knee, the greater trochanter of the femur for the hip, and the greater tuberosity of the humerus for the shoulder) as manually using APAS software.

The 3-D spatial coordinates of the digitized points were calculated using the direct linear transformation (*DLT*) procedure of the analysis system with calibration image coordinates. The mean metric transformation error values were 2.9, 1.9, and 2.7 mm for the X-, Y-, and Z-directions, respectively. The raw data were smoothed using a fourth-order Butterworth low-pass digital filter with a cut-off frequency of 4 Hz.

Calculation of the kinematic and kinetic parameters of the snatch performance

The phases were determined according to the change in the height of the barbell (Figure 3). The angular displacements of lower extremity joints (hip, knee, ankle) were calculated using Equation 1. To calculate the related angle, a, the length opposite the joint angle of segments. The *b* and *c* are other segments' lengths (proximal-distal) that compose the joint. The angular velocities of joints and the barbell vertical velocity were calculated using the central differences method (Equation 2). H_1: Barbell height at the end of the first pull, H_2: Barbell height at the end of the second pull, H_{max}: Maximum barbell height, H_{drop}: Drop distance from the maximum height of the barbell, D_1: Horizontal displacement toward weightlifter in the first pull, D_2: Horizontal displacement in the maximum height moment, D_3: Horizontal displacement toward backward after the beginning of descent from maximum height, V_1: Maximum vertical linear velocity of the barbell in the first pull, V_T: Maximum vertical linear velocity of the barbell in the transition phase, V_2: Maximum vertical linear velocity of the barbell in the second pull. *VRL*: Vertical Reference Line.

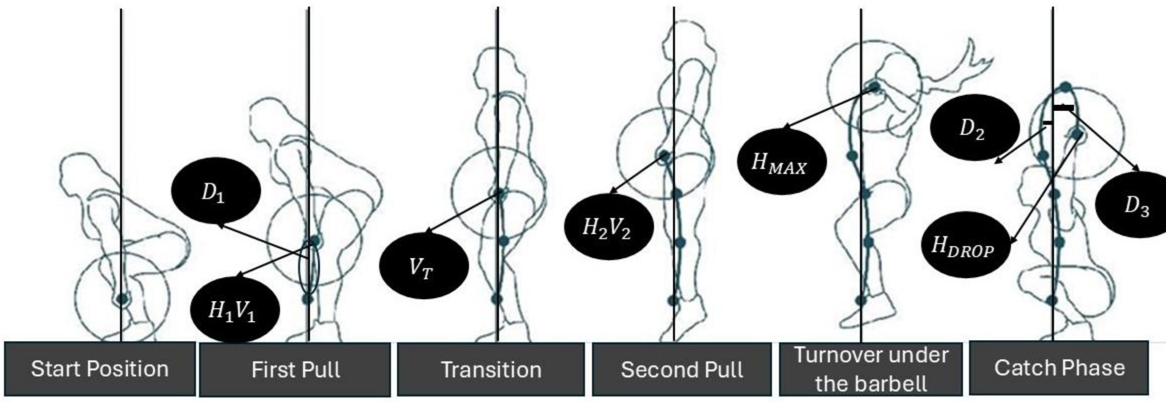


Figure 3. Phases and time instants for analysing the snatch (Zahran et al., 2025).

$$Cos\, \emptyset = \frac{b^2 + c^2 - a^2}{2bc} \quad (1)$$

$$v = \frac{x_{i+1} - x_{i-1}}{\Delta t} \quad (2)$$

Mechanical energy (*ME*) refers to the sum of the barbell's kinetic energy (*KE*) and potential energy (*PE*), which are calculated using Equations 3. Mechanical work done (*MW*) against gravity (*g*) was calculated from the changes in the barbell's mechanical energy (Equation 4) during the first ($ME_{1.\ pull}$) and second pulls ($ME_{2.\ pull}$). After the *MW* was calculated, the absolute power output (P_{absolut}) was calculated by dividing the work done during each phase by its duration (Δt). The relative work ($MW_{relative}$) and power ($P_{relative}$) values were calculated by dividing the absolute work and power values by the body mass (*BM*) in Equation 5.

$$PE = mgh\,, \qquad KE = \tfrac{1}{2}mv^2, \qquad ME = KE + PE \quad (3)$$

$$MW_{absolut} = ME_{1.Pull} - ME_{2.Pull} \qquad MW_{relative} = \frac{MW_{absolut}}{BM} \quad (4)$$

$$P_{absolut} = \frac{ME}{\Delta t} \qquad P_{relative} = \frac{P_{absolut}}{BM} \quad (5)$$

Statistical analysis

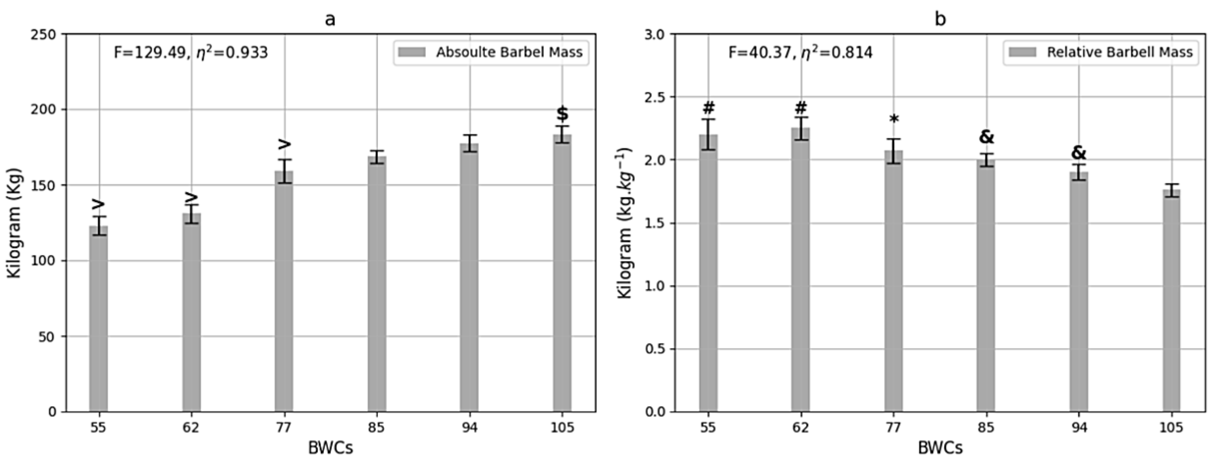
The descriptive data of weightlifters were presented in Table 1. To analyse normal distribution, the Kolmogorov-Smirnov test was used. The homogeneity of variances was tested using the Levene statistic. A one-way ANOVA was used to compare the kinetic and kinematic differences. Bonferroni correction was used as a post-hoc test for the subgroup analysis. Eta squared (η^2) was calculated to estimate the effect size (ES) for significant findings in ANOVA. The ES was examined as follows: η^2 = 0.20 – small effect, η^2 = 0.50 – medium effect and η^2 = 0.80 – large effect (Cohen, 1988). All statistical analyses were performed using the Statistical Package for Social Science version 15.0 (SPSS, Chicago, IL, USA). The level of significance was accepted as .05.

RESULTS

The comparison of absolute barbell mass (Figure 4a) and relative barbell mass (Figure 4b) showed significant differences according to BWCs. As the BWCs increased, the relative barbell mass decreased ($p < .05$). In addition, although absolute mass increases as BWCs increase, it was no significant differences between absolute barbell mass.

Table 1. The physical characteristics of elite male weightlifters in BWCs.

Body weight category	56 kg (n = 9)	62 kg (n = 8)	77 kg (n = 9)	85 kg (n = 9)	94 kg (n = 8)	105 kg (n = 9)
Age (years)	24.00 ± 2.12	25.38 ± 3.54	24.67 ± 2.96	24.89 ± 3.22	24.50 ± 2.67	27.22 ± 1.99
Body mass (kg)	55.81 ± 0.12	61.70 ± 0.17	76.68 ± 0.20	84.09 ± 0.80	93.18 ± 0.60	104.06 ± 0.53



*Note. $, different from 85-kg; #, different from 77, 85, 94, 105-kg; *, different from 94 and 105-kg, &, different from 105-kg, >, different from other BWCs, (p < .05).*

Figure 4. a) Comparison of absolute barbell mass results, b) Comparison of relative barbell mass results.

The angles of maximal flexion and extension of the joints during both pull phases revealed no significant differences (Figure 5a). However, the maximum extension angle of the knee joint was significantly greater in the 94-kg category than in the 56-kg and 77-kg categories during the first pull (F = 4.56, η^2 = 0.331, $p < .05$). In angular velocity analysis (Figure 5b), the maximum extension velocity of the knee joint in the second pull was greater in the 56-kg category than in the 105-kg category (F = 2.53, η^2 = 0.215, $p < .05$). In addition, the other angular kinematic parameters in the first pull, transition and second pull phases except for the knee joint, were not shown different.

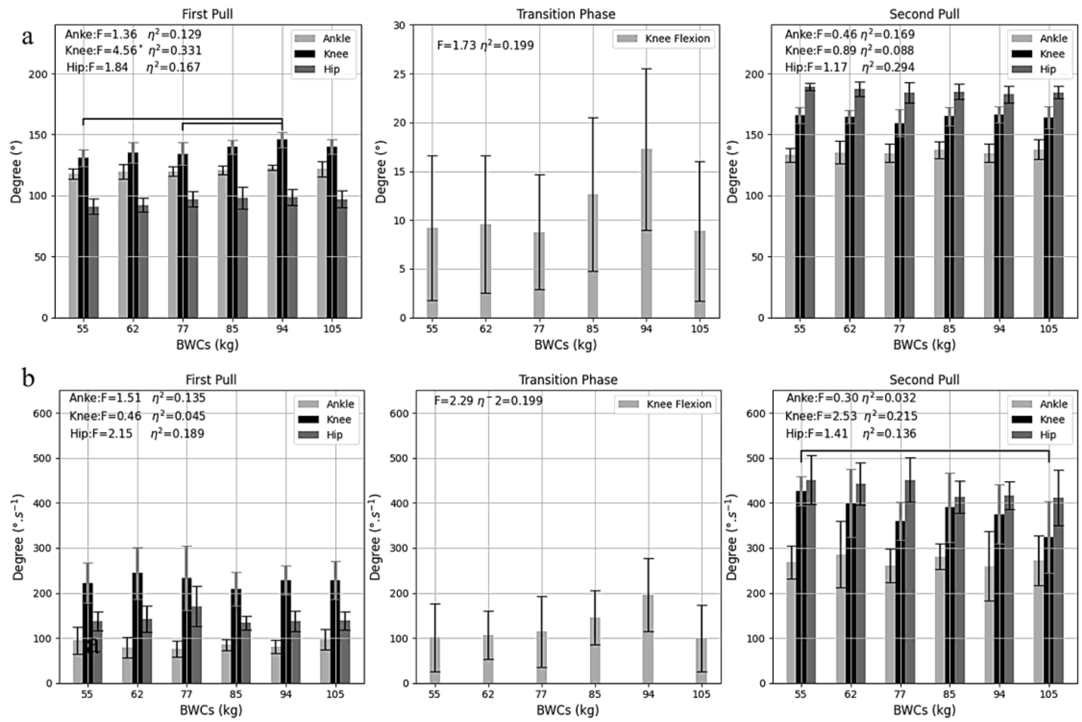


Figure 5. Angular displacement and velocity of lower limb joints in the first pull, transition phase and the second pull. a) Angular displacement of lower limb joints, b) Angular velocity of lower limb joints, $p < .05$.

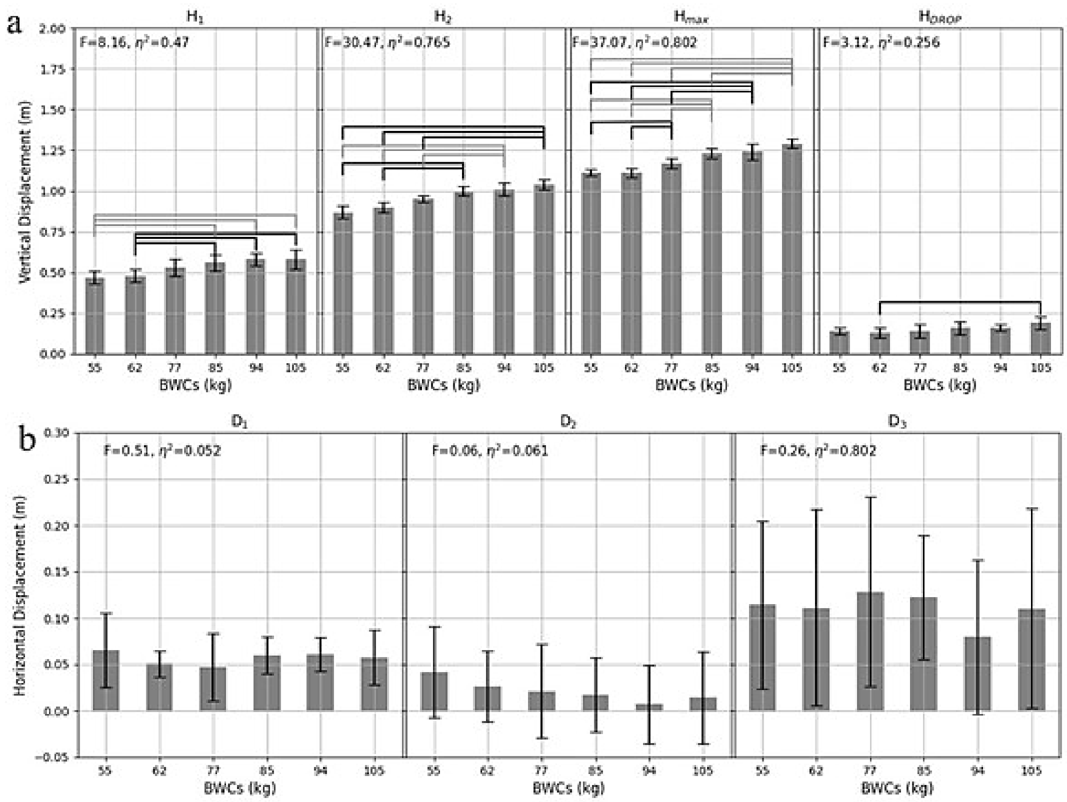


Figure 6. a) Vertical displacement of the barbell, b) Horizontal displacement of the barbell, $p < .05$.

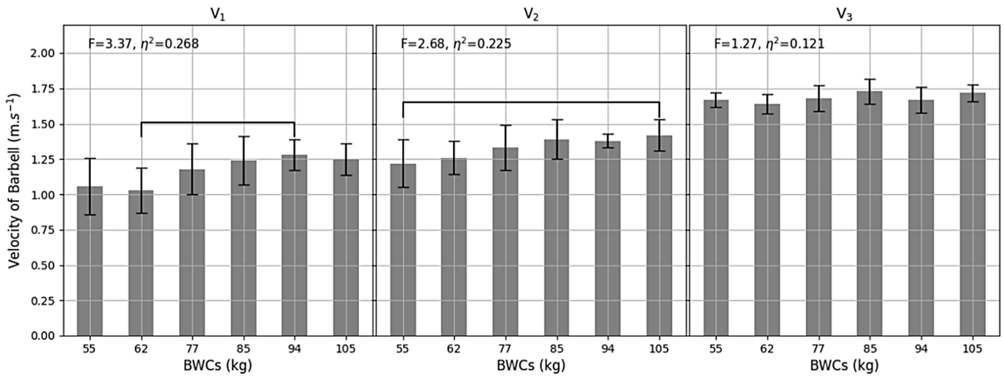
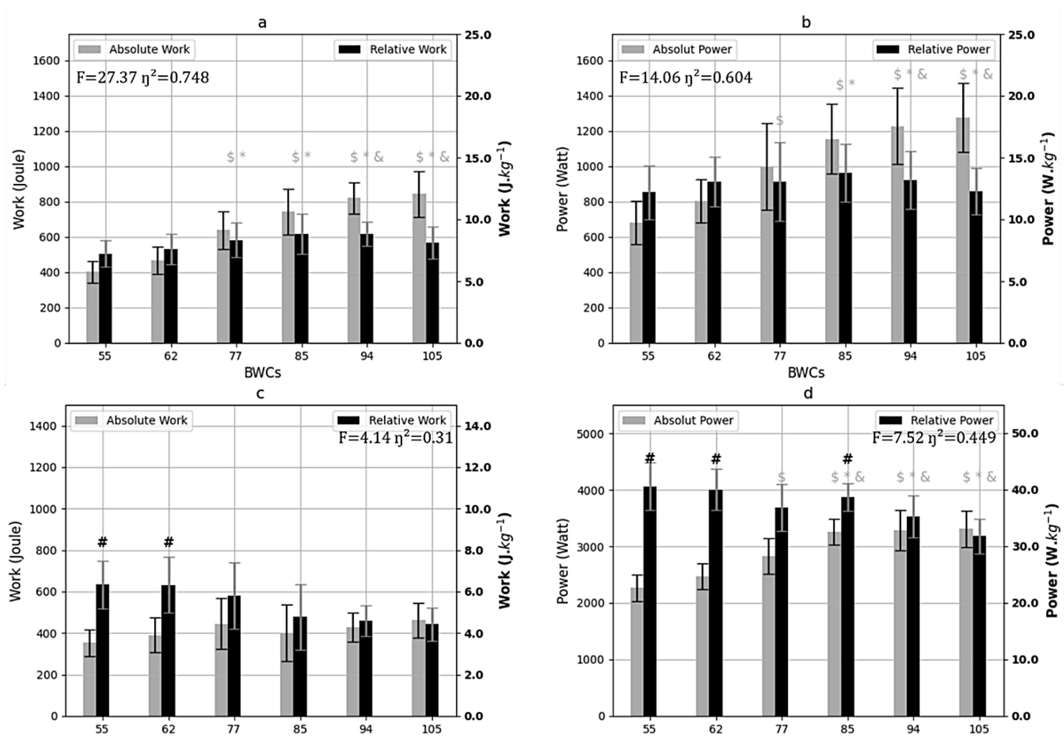


Figure 7. Vertical velocity of the barbell.

The barbell height showed significant differences. The H_1 was low in the 56 and 62-kg BWCs, according to other BWCs (F = 8.16, η^2 = 0.470, p < .05). H_2 and H_{max} were high as the BWCs increased (F = 30.47, η^2 = 0.765, F = 37.07, η^2 = 0.802, respectively). In addition, H_{drop} was different in the 105-kg from the 62-kg (Figure 6a).

Besides that, in Figure 6b, there were no significant differences in the horizontal displacement D_1, D_2 and D_3. In addition, although it was differences in the V_1 and V_T, these differences did not have high effect size. Also, the V_2 did not show statistical differences (Figure 7).



*Note. #; different from 105-kg, $; different from 55-kg, *; different from 62-kg, &; different from 77-kg. If symbols are bold style, the difference is in relative work and power results. If the symbols are grey style, the difference is in absolute work and power.*

Figure 8. Mechanical work and power output in the first pull and the second pull according to BWC. a) work results in the first pull, b) power results in the second pull, c) work results in the first pull, d) power results in the second pull.

Although MWabsolut and Pabsolut showed significant differences in the first pull, there were no significant differences in the Prelative and MWrelative (Figure 8a, 8b). As regards the second pull there were found differences in the MWrelative, Prelative, and Pabsolut outputs between BWCs (Figure 8c, 8d).

The analysis of the barbell trajectory in Figure 9 of every champion weightlifter in each BWCs showed that the H_{max} increased linearly as the weight class increased. And that the barbell moved intersecting the vertical reference line only in 62, 77, and 94-kg BWCs.

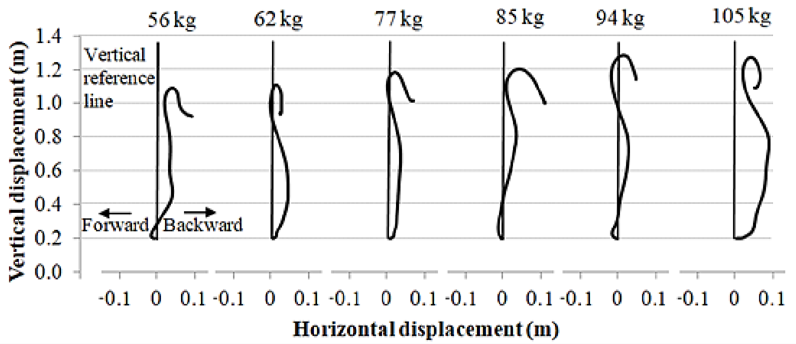


Figure 9. Barbell trajectories in the snatch lifts of the champion weightlifters.

DISCUSSION

The purpose of this study was to compare the kinetic and kinematic differences in snatch performances of elite weightlifters. As the BWCs increased, the relative barbell mass decreased. So, LWC lifted higher relative weights than MWC and HWC. However, according to $MW_{relative}$ and $P_{relative}$ in the second pull, LWC made more work and exhibited more power than 105-kg, HWC in championships. In addition, even if there were no significant differences in horizontal movement (D_1, D_2, D_3) and vertical barbell movement (V_1, V_T, V_2), the barbell height in H_1, H_2, H_{max} were shown significant differences according to BWCs. It was shown that when the WCs increased, the barbell height increased as the natural result of the weightlifters' physical differences or body sizes as reported by Arauz et al. (2025), Vidal Perez et al. (2021) and Shalmanov et al. (2015).

The DBP involves re-bending the knees during the transition phase after the barbell has been lifted above knee level (Kozub & Walker, 2022; Nagao et al., 2023). Therefore, the lower limb dynamic movements play an important role during the snatch. In the present study findings about lower limb kinetic and kinematic were not shown to have statistical differences. Cao et al. (2022) stated that elite weightlifters possess special technical characteristics. The techniques of successful snatch in the current study had a similar pattern in lower limb kinematics and kinetics. All participants were to perform that included special techniques to their maximum to become champions in the championship. And all of them were elite weightlifters. These finding were supported that report of Cao et al. (2022). Thus, it can be said about a successful lift: the successful snatch has to similar pattern during the perform as regards from BWCs.

In the snatch technique, the bar makes primarily three horizontal movements in all three trajectories. The first is toward the lifter in the first pull, the second is away from the lifter during the second pull, and the third is toward the lifter after the barbell starts to descend from the maximum height (Campos et al., 2006; Garhammer, 1993; Hoover et al., 2006; Schilling et al., 2002; Vorobyev, 1978; Whitehead et al., 2014). In the present study, the trajectory of the barbell did not cross the vertical reference line during the first pull. However, during the second pull, the trajectory intersected the vertical reference line in 24% of the LWC, 33% of the MWC, and 47% of the HWC. On average, this accounted for 35% of all lifts. The amount of forward and backward horizontal movement in the snatch technique is considered one of the most important factors influencing technical efficiency, the force applied to the barbell, and ultimately the overall success of the lift (Burdett, 1982; Garhammer, 1993; Isaka et al., 1996; Nagao et al., 2023; Stone et al., 1998). Lifting the barbell to a lower maximum height is associated with flexibility and technical skill and is considered important for successful snatching (Bartonietz, 1996; Burdett, 1982; Gourgoulis et al., 2002). World-class weightlifters gain an advantage by lifting to a lower maximum height and lowering their bodies faster, while athletes in the HWCs have a significantly higher average maximum barbell height (Burdett, 1982; Kipp et al., 2024). This suggests that LWC may have an advantage in lifting relatively heavier loads, but body size, technique and flexibility are the determinants of maximum barbell height (Arauz et al., 2024; Bartonietz, 1996; Burdett, 1982; Garhammer, 2001). In addition, as seen in Table 4, the barbell height increased as BWCs increased, supporting the literature in the first and second pull. However, the horizontal displacement movements showed similar results in all BWCs. Nagoa et al. (2023) and Musser et al. (2014)'s results supported the present study results.

The lifter is relatively slow pulling the barbell during the first pull because lifters need to produce considerable work over a long period to overcome the inertia of the barbell (Gourgoulis et al., 2000; Sandau et al., 2022; Sandau et al., 2023). Thus, the first pull is strength-oriented, while the second pull is faster and power-oriented (Garhammer, 1991). Similarly in this study, mechanical work and power output in the first pull, as well as absolute power output in the second pull, were greater in the MWC and HWC than in the LC. In contrast, the relative power output in the second pull was greater in the LWC compared to the other categories. Several earlier studies that compared barbell and body kinematics across different BWCs reported that HWC tended to perform more mechanical work, lift the barbell faster, and generate higher power outputs due to the increased weight lifted (Garhammer, 1991; Garhammer, 2001; Kipp et al., 2011; Nagao et al., 2023; Sandau et al., 2022; Souissi et al., 2021). Campos et al. (2006) found that young male HWC (85 and 105-kg) were more efficient during the initial pull due to longer barbell pushing trajectories. LWCs were able to lift relatively heavier weights because they did not have the greater challenge that HWCs had to overcome. However, as the level of technical skill increases, unnecessary energy consumption can be reduced by maintaining optimal barbell height.

CONCLUSION

In the present study, no significant differences were found in the lower limb kinematics between BWCs, except for the greater knee extension velocity observed during the second pull in the LWC. These findings suggested that elite weightlifters had similar technical skills in high-level snatch performance. On the other hand, unlike HWC, LWC generated higher power output during the second pull even though they lifted heavier relative weights; this was related more to the lower maximum barbell height than to its vertical velocity. The reason is that LWC had an advantage in the snatch technique in terms of barbell height, so they needed more power than strength when compared to HWC. This observation suggested that lower barbell height and higher power output during the second pull might be clues for successfully lifting higher weights in the snatch technique. Therefore, training programs designed to increase power in the second pull and improve skill levels could help weightlifters lift heavier weights successfully.

AUTHOR CONTRIBUTIONS

All authors contributed equally to the article's design, data collection, analysis and writing stages.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL CONSIDERATIONS

All participants signed an informed consent form during the championship in accordance with the declaration of Helsinki. The study was approved by the local ethics committee of the Faculty of Sport Sciences of Selçuk University (Date and approval number: 28/01/2022, 22).

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