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Research article

Effects of different drop height training on lower limb explosive, anaerobic power, and change of direction performance in Chinese elite female wrestler

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ABSTRACT

Objective: The purpose of this study was to explore the effects of an 8-week drop jump (DJ) training program at varying heights on lower limb strength, anaerobic power, and change of direction (CoD) abilities in elite female Chinese wrestlers.
Methods: The drop jump (DJ) training program was conducted at varying heights of 20, 40, 60, and 80 cm. The study involved 40 elite female wrestlers who were divided into five groups respectively: Control, DJ20, DJ40, DJ60, and DJ80. Participants engaged in an 8-week structured training program that incorporated drop jumps at the assigned heights for each group.
Results: The results demonstrated significant enhancements in explosive strength and anaerobic power, particularly with DJ40 to DJ60 ($d = -2.48$ to -5.54), and in CoD performance across all DJ groups ($d = 1.07$ to 5.25), showcasing a dose-response effect.
Conclusions: Optimal training effects for lower limb strength and power were found at drop jump heights of 40–60 cm, while heights of 60–80 cm yielded the most significant improvements in CoD performance. This highlights the specificity of DJ training heights in enhancing athletic performance among elite female wrestlers.

1. Introduction

Wrestling is one of the oldest combat sports practices that comes back to 708 BC in the ancient Greek Olympic Games [1]. In these contact sports, a high fitness level requires complex skills and tactical excellence for success [2]. For wrestlers, success is contingent upon various key factors, including strength, speed, explosive performance, and anaerobic power, with particular emphasis on the capacity to generate force rapidly or at high velocities. The anaerobic energy level is critical for judging the final wrestling combat result [3]. This is because the determinant moments of the match are mainly associated with the energy provided by the anaerobic energy systems [4]. Moreover, within the competitive arena, wrestlers must capitalize on ephemeral opportunities and execute timely offensive and defensive actions. With superior explosive strength and change of direction (CoD) performance, wrestlers are adept at

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attaining optimal offensive positioning and dynamically adjusting their center of gravity, thereby enabling them to effectively engage opponents with heightened speed and precision.

Plyometric training (PT) is a well-known form of "ballistic training," which refers to a wide range of jumping, bounding, and hopping exercises involving high-intensity stretching of a muscle (eccentric contraction) immediately followed by a rapid and powerful concentric contraction of the same muscle and connective tissue [5]. As PT can produce more force than can be provided by a concentric-only muscle action alone, researchers have shown that PT is an effective method for improving jumping abilities [6,7], balance [8], explosive performance [8,9], anaerobic power [10], strength [8,11], speed [12], agility [13,14], and CoD ability [15,16]. Among the various types of PT, drop jump (DJ) represents one of the most frequently applied jump training aimed at improving lower limb explosive performance, speed, anaerobic power, and jump heights [10,17]. DJ training is a specific type of plyometric training that involves a controlled descent from a predetermined height, where the athlete immediately transitions from landing to jumping, effectively enhancing explosive power through eccentric-concentric movements [18,19]. DJ training activates specific physiological adaptations due to its unique biomechanical demands, particularly in muscle-tendon interactions and neuromuscular efficiency, while also enhancing coordination, speed, and strength through personalized training with varied drop heights. These adaptations are essential for improving wrestling performance, particularly where agility and explosive power are critical for effectively manipulating opponents and maintaining balance during intense physical confrontations [20]. The intensity of DJ is determined by the eccentric load, which is directly affected by the exposure time of gravitational acceleration. Therefore, drop height is considered the key variable for practitioners to reduce or increase the training intensity of the DJ [21]. High drop height increases the impact velocity, which may subsequently produce large impact peaks and loading rate if the task exceeds the eccentric force generation capacity of the athlete [22].

To avoid such an eventuality, it is best to use an optimal drop height to maximize performance adaptability and minimize the risk of injury. However, there is controversy about the optimal drop height. Several studies specified a drop height of 40 cm as the optimal drop height for all participants [23,24], but this might fail to reach the eccentric strength threshold of some athletes. In addition, Decker et al. [25] reported that target heights in the 60- to 80-cm range are suitable to produce more power than those in the 40-cm range. Furthermore, Viitasalo et al. [26] investigated the effects of 40-cm and 80-cm DJ training on vertical jumping height and neuromuscular functioning in highly trained triple jumpers; their results showed that the triple jumpers jumped higher in the 80-cm group, had shorter braking and total contact times, and had greater average and peak vertical ground reaction forces. Moreover, Marina et al. [27] reported that compared with 20-, 40-, 60-, and 100-cm drop heights, the best gymnasts (finalists at the World Championship) obtained their best performance at the 80-cm drop. Recently, Li Gen et al. [28] reported that 60 cm may be the optimal drop height to improve the lower limb explosive and CoD performance in collegiate Sanda athletes. However, Sanda athletes emphasize high jumps and quick lateral movements, while wrestling athletes prioritize sustained explosive strength and reactive change of direction in grappling. This divergence in training highlights the unique physiological requirements and strategic approaches of each discipline, underscoring the need for tailored research in wrestling.

Although previous studies have reported the characteristics of lower limb muscle strength of wrestlers [29], to our knowledge no studies are addressing different drop height training on lower limb explosive, anaerobic power, and CoD performance in elite female wrestlers. Considering that different DJ heights have different effects on lower limb explosive, anaerobic power, and CoD performance, the present study aimed to examine the effects of 8-weeks of DJ executed from 20-, 40-, 60-, and 80-cm height boxes on lower limb explosive, anaerobic power and CoD performance in Chinese elite female wrestlers, thus holding promise as an effective strength and conditioning training strategy for elite female wrestlers. This study hypothesizes that an 8-week training program utilizing different drop heights will significantly enhance lower limb explosive power, anaerobic power, and CoD performance in Chinese elite female wrestlers.

2. Methods

2.1. Participants

Forty elite female wrestlers participated in the tests who had the following characteristics (Table 1). The inclusion criteria: participants were physically healthy, free from severe lower-body injuries related to anterior cruciate ligament (ACL), hamstring, meniscus, and ankle, or any medical and orthopedic problems on any body part within the last 6 months. The participants were randomly allocated into 5 groups: Con, DJ20, DJ40, DJ60, and DJ80. All participants voluntarily participated in this study. Both participants and coaches were informed of the potential risks and benefits of the tests. The study procedures adhered to the tenets of the Declaration of Helsinki, were approved by the Ethics Committee of the China Institute of Sport Science (Approval number: CISSLA-

Table 1
Participants' physical characteristics(n = 40).

	Controls(n = 8)	DJ20(n = 8)	DJ40(n = 8)	DJ60(n = 8)	DJ80 (n = 8)
Age(years)	26.50 ± 3.74	24.50 ± 3.07	25.75 ± 3.41	26.63 ± 2.33	26.38 ± 4.03
Height(cm)	157.15 ± 2.08	161.31 ± 2.92	164.00 ± 2.45	168.53 ± 4.38	171.14 ± 2.39
Weight(kg)	55.03 ± 1.87	58.86 ± 2.33	63.79 ± 3.80	71.78 ± 5.48	79.14 ± 4.08
BMI index	21.05 ± 0.77	22.58 ± 0.99	23.70 ± 1.45	25.30 ± 2.04	27.00 ± 1.53
Training experience(years)	11.50 ± 3.30	10.63 ± 2.67	11.88 ± 1.96	12.25 ± 2.12	12.38 ± 3.07

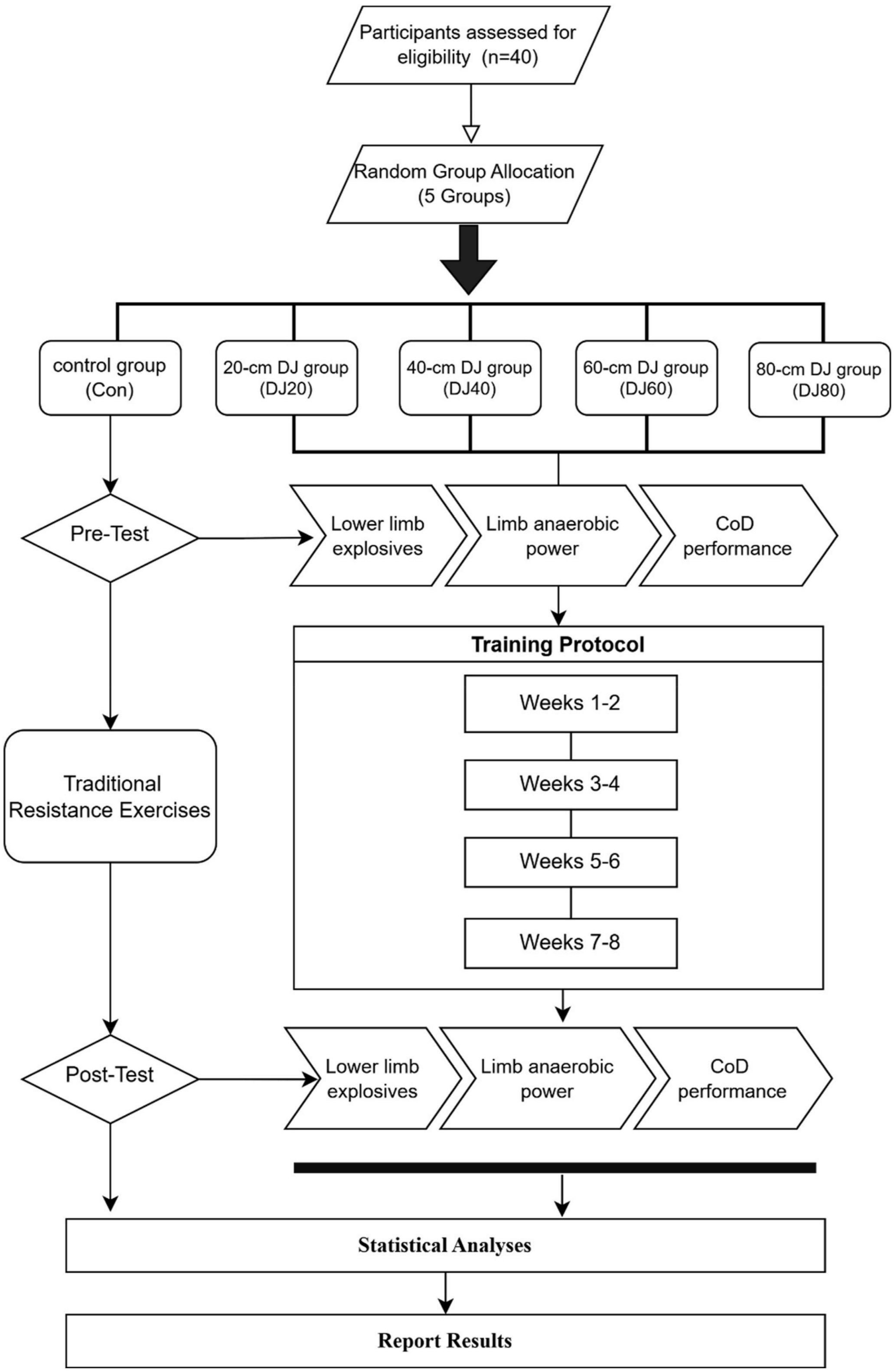

Fig. 1. Flow chart depicting the experimental design of the study.

20221104), and involved obtaining written informed consent from the athletes before they participated in the tests.

2.2. Study design

In this study, participants were randomly allocated into 5 groups as follows: control group (Con), 20-cm DJ group (DJ20), 40-cm DJ group (DJ40), 60-cm DJ group (DJ60), and 80-cm DJ group (DJ80). Participants in DJ20, DJ40, DJ60, and DJ80 received 20 cm DJ training, 40 cm DJ training, 60 cm DJ training, and 80 cm DJ training for 8 weeks, respectively. The control group is mainly based on traditional resistance exercises (e.g. deep squats, split squats, front squats, holding squats, and snatch) and was used to account for any changes in performance that may have occurred for the study. Before and after an 8-week training period, participants were assessed by several tests, which were performed by the same investigators who were blinded to the intervention. The experimental design is illustrated in the flow diagram presented in Fig. 1.

2.3. Experimental trials

Table 2 is the training schedule of DJ20, DJ40, DJ60, and DJ80 protocols, all DJ training sessions lasted about 35–40 min and were performed after a 15-min warm-up. For week 1 and week 2, all DJ training sessions included 5 sets of 8 repetitions of DJ from either 20-, 40-, 60-, or 80-cm height boxes (i.e., 40 contacts), with 120 s of rest between sets. For week 3 and week 4, the number of repetitions increased to 12 (i.e., 60 contacts). With the participants improved, the number of repetitions increased to 15 (i.e., 75 contacts) for week 5 and week 6. Finally, the number of repetitions increased to 20 (i.e., 100 contacts) for week 7 and week 8.

Participants were provided with instructions to execute maximal vertical jumps with minimal ground contact time in order to optimize reactive strength. At the end of the training session, effective static stretching techniques or foam rolling were performed for a 15-min cool-down. The training frequency was three times a week, with a minimum interval of 48 h, on Monday, Wednesday, and Friday.

Based on previous studies, we chose the standing long jump (SLJ) and the countermovement jump (CMJ) to test the effect of DJ on lower limb explosives [16,23]. Wingate anaerobic test to test the effect of DJ on lower limb anaerobic power [30]. The Illinois agility test, the L-run test, the 505 agility test, and the T-test to test the effect of DJ on CoD performance [31]. The four CoD tests are depicted in the schematic diagram presented in Fig. 2. All tests are divided into two days. SLJ, CMJ, Illinois agility test, the L-run test, 505 agility test, and T-test were done on the first day, and the Wingate anaerobic test on the second day. Before testing, participants underwent familiarization training to minimize the impact of learning on testing. All tests were conducted in the wrestling venue at the Guangxi Combat Sports Training Center. which is fully equipped and suitable for multiple people for test at the same time. Before the test, the physical trainers prepared the test field and equipment according to the group of subjects. During the testing process, five groups of 8 participants, and each group was conducted by one experienced wrestling coach and one recorder, and each group was tested simultaneously according to the test content and order. On the initial day of assessments, the examinations were bifurcated into morning and afternoon sessions. The morning assessments encompassed the SLJ, and CMJ, whereas the afternoon evaluations comprised the Illinois agility test, The L-run test, the 505-agility test, and the T-test. The Wingate anaerobic test of the second day was divided into morning and afternoon sessions, each part consisting of 20 subjects. There was a 15-min interval between each test to avoid the effects of fatigue on the test results. The twice tests were conducted under the same conditions. Participants were instructed not to engage in vigorous exercise 24 h before the test, and there were no other sports activities on the day of the test. Additionally, athletes completed a standardized warm-up routine before testing.

Table 2
Training schedule of DJ20, DJ40, DJ60 and DJ80 protocols.

Week	Group	Jump height(cm)	Repetition/set	sets	Rest between sets(s)
1–2	DJ20	20	8	5	120
	DJ40	40	8	5	120
	DJ60	60	8	5	120
	DJ80	80	8	5	120
3–4	DJ20	20	12	5	120
	DJ40	40	12	5	120
	DJ60	60	12	5	120
	DJ80	80	12	5	120
5–6	DJ20	20	15	5	120
	DJ40	40	15	5	120
	DJ60	60	15	5	120
	DJ80	80	15	5	120
7–8	DJ20	20	20	5	120
	DJ40	40	20	5	120
	DJ60	60	20	5	120
	DJ80	80	20	5	120

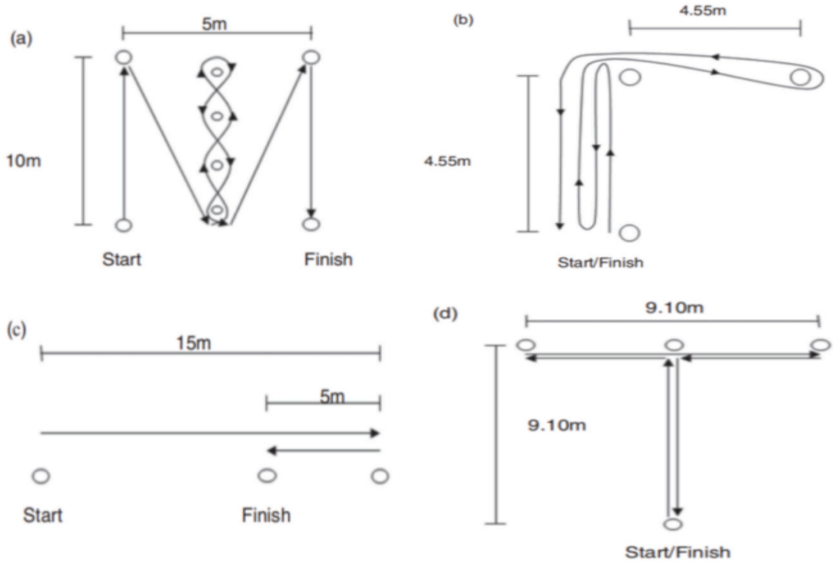

Fig. 2. A schematic of the four CoD tests used within this study.
Note: (a) = Illinois Test, (b) = L-Run Test, (c) = 505 Agility Test, (d) = T-Test.'

2.4. Procedures

2.4.1. Standing long jump test

The SLJ is a common test to measure the explosive performance of the lower limb, which was administered as Yasue et al. [32]. previously described: First, shake the arm sufficiently and recoil. Second, jump with the knees tightly bent. finally, put the feet out front while holding the knees. The jump is assessed by the horizontal distance from the takeoff line to the heel or the point of contact nearest to the takeoff line at landing. A rest period of 60 s was allowed between Trails and the best out of three Trails was retained for further analysis.

2.4.2. Countermovement jump test

The CMJ was performed with the participant standing in an upright erect position on the EZEJUMP vertical jump testing system (Swift Performance, Australia) with the hands on the hips to avoid arm swings. A fast-downward movement was performed by flexing the knees and hips before rapidly extending the legs and performing a vertical jump as high as possible. A rest period of 60 s was allowed between Trails and the best out of three Trails was retained for further analysis.

2.4.3. Wingate anaerobic test

Wingate anaerobic test(WAnT) was performed with a specific cycle-ergometer (Monarch, Peak Bike 894e, MONARK, Sweden), according to the protocol used by Inbar et al. [30]. Participants were adjusted on the cycle ergometer (the seat higher in relationship to the length leg and the distance of the handlebar [33]. Before the start of WAnT, participants performed a general warm-up (<50 % VO2max) composed of jogging, walking, and stretching for about 15 min followed by a specific cycling exercise (5-min in the cycle ergometer with a load of 35 W). The test started 2-min after the warm-up. WAnT was performed at maximal intensity for 30s with a load corresponding to 7.5 % of body mass (previously calculated). Resistance was applied after 3s and the revolution per minute reached almost 70 of maximal acceleration with no load. Participants were instructed to remain seated throughout the test and received verbal encouragement to sustain their maximum effort throughout the test. One minute of cycling with no load was included at the end of the test. The following variables were obtained in WAnT with the Monark Software (Monark ATS Software, MONARK, Sweden).

2.4.4. Illinois agility test

The Illinois agility test was set up and administered using the protocol outlined by Hoffman [34]. The subjects were instructed to lie on their stomachs, with their head just behind the start line and hands by the shoulders. On the "Go" command, the participant got up and sprinted the course as indicated in Fig. 2. The participants were required to touch the cones opposite the start and finish line and run in and out of (slalom) the cones down the middle of the course.

2.4.5. The L-run test (aka three-cone drill)

The L-Run was set up and administered using the protocol outlined by Reiman and Manske [35]. The subjects started in a standing two-point stance, and upon the "Go" command were required to sprint forward 4.55 m, touch the cone with either hand, and sprint back to the start line. Next, the subjects reversed direction and sprinted around the first cone, cut right, and circled the second cone, ensuring that the cone was on the left-hand side of the body. The test was completed when the participant sprinted through the start/finish line.

2.4.6. 505 agility test

The 505-agility test was set up and administered using the protocol outlined by Draper and Lancaster [36]. On the “Go” command, the subjects were instructed to sprint for 15 m (through the timing gates at 10 m), turn on their preferred foot, and sprint back through the timing gates.

2.4.7. T-test

The T-test was set up and administered using the protocol outlined by Semenick [37]. Upon the “Go” command, the subjects were instructed to sprint forward 9.10 m, touch the cone with their right hand and without crossing their feet, side shuffle 4.55 m to the left, and touch the cone with their left hand. The subject then shuffles to the right 9.10 m, touches the cone with their right hand, and returns to the center cone by side shuffling 4.55 m. The subject then touches the center cone with their left hand and backpedals 9.10 m through the finish line, ensuring that balance is maintained.

2.5. Statistical analyses

The data will be represented using mean values and standard deviations. A paired *t*-test will be used to evaluate the within-group differences in various parameters before and after the athletic training intervention, reporting 95 % confidence intervals (CI), t-values, p-values, and Cohen’s d values. Changes in each test parameter for the athletes before and after the test will be represented as percentage differences, calculated using the formula: Percentage Difference = (Pre-test - Post-test)/Pre-test*100. An independent samples *t*-test will be used to assess the inter-group differences in the magnitude of each test parameter between the Control (Con) group and the DJ20, DJ40, DJ60, and DJ80 groups. The effect sizes for intra-group and inter-group comparisons will be denoted using Cohen’s d, categorized as:< 0.2 as trivial, 0.2–0.6 as small, 0.6–1.2 as moderate, 1.2–2.0 as large, and >2.0 as very large [38]. Python version 3.12.0 will be utilized for data analysis and visualization. The level of significance will be set at $P < 0.05$.

3. Results

3.1. Effects of DJ training on lower limb explosive and anaerobic power performance

Table 3 presents the descriptive statistics of all lower limb explosive and anaerobic power. The results showed that no statistically significant differences in control groups were found for all test parameters($p > 0.05$). Compared with the control group, the SLJ, CMJ, and LowerAna in the DJ20 group showed only trivial to small differences (d = −0.06 to 0.44) before and after the training intervention, The SLJ and CMJ of the DJ40-80 group showed very large differences before and after training intervention (d = −2.48 to −5.54), The LowerAna of the DJ40-80 group showed moderate to large differences (d = −1.07 to −1.38) before and after training intervention.

3.2. Effects of DJ training on CoD performance

As shown in Table 4, for the Illinois agility test, the L-run test, 505 agility test, and *t*-test. both the control group and the experimental group (DJ20-80) had a significant effect on CoD performance, there is a moderate to very large difference (d = 1.07 to 5.25) in the pre-and post-tests.

Table 3
Descriptive statistics of lower limb explosive and anaerobic power test results before and after the 8-week training intervention.

Variable	Group	Pre	Post	95%CI	t	P	Cohen’s d
SLJ(m)	Con	2.24 ± 0.07	2.24 ± 0.07	0(-0.03,0.02)	−0.23	0.82	−0.08
	DJ20	2.22 ± 0.13	2.22 ± 0.11	0(-0.02,0.02)	0	1	0.07
	DJ40	2.08 ± 0.09	2.19 ± 0.06	−0.11(-0.15,-0.08)	−7.36	0	−2.6
	DJ60	2.18 ± 0.09	2.24 ± 0.07	−0.07(-0.08,-0.05)	−7.89	0	−2.79
	DJ80	2.19 ± 0.06	2.29 ± 0.03	−0.1(-0.13,-0.07)	−7.41	0	−2.62
CMJ(m)	Con	0.34 ± 0.03	0.34 ± 0.03	0(0,0.01)	0.71	0.5	0.25
	DJ20	0.34 ± 0.05	0.34 ± 0.05	0(0,0)	−2.02	0.08	−0.06
	DJ40	0.30 ± 0.04	0.34 ± 0.03	−0.04(-0.05,-0.03)	−7.02	0	−2.48
	DJ60	0.32 ± 0.05	0.40 ± 0.04	−0.07(-0.09,-0.06)	−15.68	0	−5.54
	DJ80	0.33 ± 0.05	0.40 ± 0.04	−0.07(-0.09,-0.06)	−10.75	0	−3.8
LowerAna (w/kg)	Con	5.63 ± 0.55	5.66 ± 0.54	−0.04(-0.12,0.05)	−0.93	0.39	−0.33
	DJ20	5.79 ± 0.74	5.78 ± 0.74	0.01(-0.01,0.04)	1.23	0.26	0.44
	DJ40	5.74 ± 0.48	5.85 ± 0.43	−0.1(-0.16,-0.04)	−3.91	0.01	−1.38
	DJ60	5.90 ± 0.43	6.11 ± 0.39	−0.21(-0.36,-0.07)	−3.44	0.01	−1.21
	DJ80	5.89 ± 0.50	6.07 ± 0.38	−0.18(-0.32,-0.04)	−3.04	0.02	−1.07

Note: SLJ, standing long jump; CMJ, counter movement jump; LowerAna, lower anaerobic power; ES, effect size; DJ, drop jump.

Table 4
Descriptive statistics of CoD test results before and after the 8-week training intervention.

Variable	Group	Pre	Post	95%CI	t	P	Cohen's d
IAT (s)	Con	16.51 ± 0.71	15.93 ± 0.75	0.59(0.26,0.91)	4.29	0	1.52
	DJ20	16.14 ± 0.64	15.10 ± 0.68	1.04(0.72,1.36)	7.62	0	2.69
	DJ40	16.13 ± 0.32	14.41 ± 0.36	1.71(1.42,2)	13.91	0	4.92
	DJ60	15.71 ± 0.39	14.66 ± 0.31	1.05(0.88,1.22)	14.85	0	5.25
	DJ80	16.26 ± 0.41	14.70 ± 0.40	1.56(1.13,1.99)	8.58	0	3.03
LRT (s)	Con	5.78 ± 0.24	5.64 ± 0.31	0.07(0.02,0.13)	3.03	0.02	1.07
	DJ20	5.66 ± 0.33	5.11 ± 0.12	0.36(0.28,0.45)	10.24	0	3.62
	DJ40	5.64 ± 0.27	5.08 ± 0.12	0.33(0.24,0.41)	8.88	0	3.14
	DJ60	5.60 ± 0.35	4.67 ± 0.09	0.81(0.63,1)	10.51	0	3.72
	DJ80	5.58 ± 0.32	4.55 ± 0.20	0.89(0.75,1.04)	14.67	0	5.19
505AT (s)	Con	2.68 ± 0.19	2.61 ± 0.14	0.14(0.05,0.23)	3.73	0.01	1.32
	DJ20	2.64 ± 0.16	2.27 ± 0.11	0.55(0.3,0.8)	5.15	0	2.02
	DJ40	2.58 ± 0.16	1.77 ± 0.14	0.93(0.65,1.22)	7.84	0	2.77
	DJ60	2.61 ± 0.14	2.28 ± 0.18	0.56(0.4,0.72)	8.33	0	2.94
	DJ80	2.53 ± 0.21	1.64 ± 0.07	1.04(0.67,1.41)	6.63	0	2.34
TT (s)	Con	9.05 ± 0.50	8.91 ± 0.47	0.15(0.07,0.22)	4.41	0	1.56
	DJ20	9.10 ± 0.49	8.26 ± 0.36	0.84(0.49,1.19)	5.64	0	2.03
	DJ40	9.04 ± 0.43	8.38 ± 0.26	0.65(0.39,0.92)	5.85	0	2.07
	DJ60	9.14 ± 0.39	7.95 ± 0.30	1.19(0.87,1.51)	8.67	0	3.06
	DJ80	9.38 ± 0.48	8.45 ± 0.25	0.93(0.71,1.15)	9.98	0	3.53

Note: IAT, illinois agility test; LRT, L-run test; 505AT, 505 agility test; TT, *t*-test; ES, effect size; DJ, drop jump; CoD, change of direction.

3.3. Percentage difference in SLJ, CMJ, and LowerAna before and after testing

The results indicated (Fig. 3) that the control group and the DJ20 group exhibited only trivial to small differences in SLJ, CMJ, and LowerAna after the training intervention (d = −0.08 to −0.33). Significant differences were observed in SLJ and CMJ in the DJ40-80 groups post-intervention (d = −2.48 to −5.54). In the comparison of LowerAna pre- and post-training in the DJ40-80 groups, moderate to large differences were noted (d = −1.07 to −1.38). In terms of the magnitude of change due to the training intervention, compared to the control group (Con), SLJ and CMJ showed trivial differences (d = 0.07, −0.06), indicating the limited impact of DJ20 on these two metrics. However, the DJ40, DJ60, and DJ80 groups demonstrated very large differences in SLJ (d = −2.86, −2.79, −2.28) and CMJ (d = −3.04, −5.92, −3.45), suggesting significant improvements in these metrics with increasing training intensity. Compared to the control group (Con), LowerAna showed a moderate difference (d = 0.44, −0.03), implying that the enhancement in lower limb anaerobic capacity was limited with DJ20. In contrast, the DJ40, DJ60, and DJ80 groups all displayed moderate differences (d = −0.70, −1.18, −1.00), indicating a significant improvement in lower limb anaerobic capacity with increased training intensity.

3.4. Percentage difference in CoD before and after testing

The results demonstrated (Fig. 4) that in the four agility tests - Illinois Agility Test (IAT), the L-Run Test, the 505 Agility Test, and the T-Test - significant impacts on lower limb agility were observed both in the control group and across different DJ training intensities, with post-training performances markedly superior to pre-training. Medium to very large differences were noted in pre- and post-test comparisons (d = 1.07 to 5.19). Compared to the control group (Control), completion times were significantly reduced in the DJ20, DJ40, DJ60, and DJ80 groups, showing large to very large differences (d = 1.26, 1.71, 3.22, 2.26). This indicates that as training intensity increased, athletes' performances in the IAT significantly improved. For the 505 Agility Test (505AT), compared to the control group, all DJ groups (DJ20, DJ40, DJ60, DJ80) significantly outperformed the Con group, demonstrating very large differences (d = 3.91, 2.99, 5.30, 8.94), suggesting that the training was highly effective in enhancing performance in 505AT. Compared to the Con group, DJ20 showed a large difference (d = 1.88), indicating that even lower-intensity training could significantly improve L-Run Test (LRT) performance. Medium to high-intensity training (DJ40, DJ60, DJ80) compared to the Con group showed very large differences (d = 2.88, 3.58, 3.21), indicating more pronounced improvements in LRT performance with increasing training intensity. The T-test (TT) performances in DJ20, DJ40, DJ60, and DJ80 were all superior to the Con group, with very large differences (d = 2.31, 2.41, 4.06, 4.56), demonstrating that all levels of training intensity effectively improved the athletes' overall reaction times.

4. Discussion

In high-level wrestling competitions, lower limb explosive, anaerobic power, and CoD are key determinants of athlete performance [29]. These abilities not only have a direct impact on the athlete's quick start, deceleration, movement speed, and power output during a match, but are also important to seize the transient opportunities and take timely offensive and defensive actions. To the best of our knowledge, this is the first study to investigate the effects of DJ training with different DJ heights on lower limb explosive power, anaerobic power, and CoD performance in elite female wrestlers.

Comparing the experimental group with the control group after 8 weeks of DJ training, we found that the experimental group showed significant improvements in lower limb explosive strength, anaerobic power, and CoD. In particular, there was a trend towards

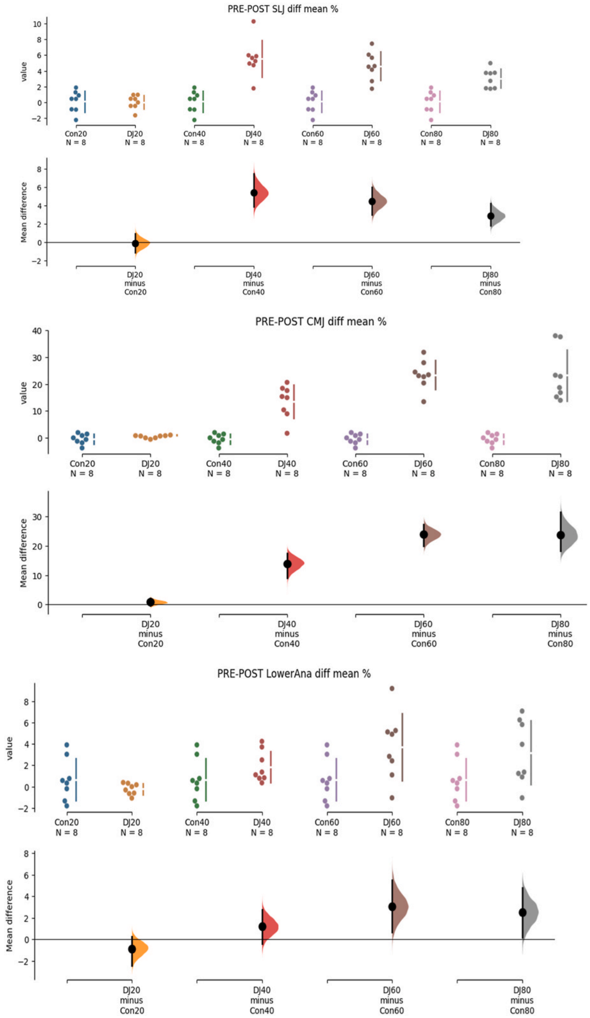

Fig. 3. Effectiveness of the percentage difference ratio between SLJ, CMJ, and LowerAna before and after testing on Con and DJ20-80 cm. Note: (a) = SLJ, (b) = CMJ, (c) = LowerAna.

a significant dose effect at the DJ height range of 40–80 cm.

Eight weeks of DJ training had a significant effect on improving lower limb explosive strength (CMJ and SLJ) and anaerobic power in elite female wrestlers. The DJ training group performed better on these metrics than the control group on traditional apparatus resistance exercises (e.g. deep squats, split squats, front squats, holding squats, and snatch). Traditional lower limb resistance training focuses on hip and knee flexion and extension and emphasizes the development of muscle strength. Alternatively, among the different training forms of PT, DJ is acknowledged as one of the most commonly implemented jump training protocols aimed at improving lower limb explosive performance, speed, and jump heights through box jumping training at different heights [17], with an emphasis on rapid neuromuscular pre-activation, rapid contraction of muscle fibers in a short time and power output capacity. This exercise involves a repeated series of bouts, each comprising a rapid deceleration of the body, followed immediately by a brief transition phase and rapid acceleration in the opposite direction. This rapid combination of eccentric and concentric muscular activity involves the stretch-shortening cycle (SSC), which provides a physiological advantage in that the muscular force developed during the concentric phase is potentiated by the preceding eccentric action [39,40]. Therefore, DJ training can significantly increase lower limb muscular strength in the short term by increasing muscle fiber contraction [41,42] and by improving the supply of energy metabolic systems (particularly the ATP-CP system), which in turn significantly improves power output [43] and energy supply of lower limb muscular strength [44] in athletes in the short term. The improvement in lower limb explosive strength and anaerobic power performance induced by DJ training may result from neuromuscular adaptations and improvements in the energy system. Previous studies have shown that 6 weeks of DJ training significantly improved CMJ and SLJ performance in collegiate Sanda athletes [28], and the other study further demonstrated that PT training significantly improved lower extremity explosive strength and anaerobic power performance in Female Futsal players [10]. These findings are consistent with ours, suggesting that DJ training has a potentially positive effect in improving lower limb explosive strength and anaerobic power with potential beneficial effects.

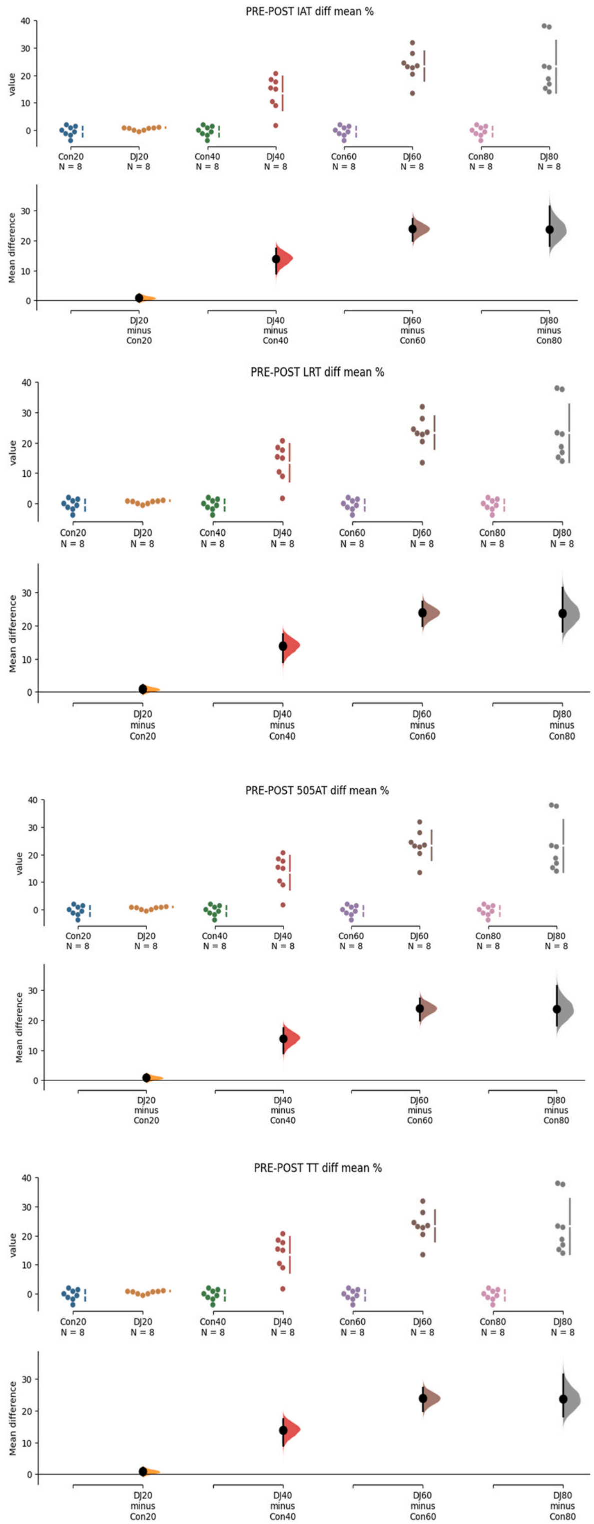

Fig. 4. Effectiveness of the percentage difference ratio between the Illinois agility test, L-run test, 505 agility test, and T-test before and after DJ training.
Note: (a) = Illinois Test, (b) = L-Run Test, (c) = 505 Agility Test, (d) = T-Test.

The results of this study further confirmed that DJ training has a significant effect on improving lower limb CoD performance in athletes. Improvements in CoD performance can be attributed to many factors. Firstly, DJ training significantly improves the explosive power of the lower limb muscles through the rapid contraction of muscle fibers, which enables athletes to generate faster movement speeds during a change of direction [12]. Secondly, DJ training also helps to improve the reaction speed and coordination of the nervous system [13,14], which is essential for fast and accurate changes of direction. In addition, DJ training helps to improve muscle strength and movement efficiency [45], thereby reducing the time the lower limbs contact with the ground and improving the athlete's CoD ability [15,16]. Finally, high-intensity DJ training also requires strong core stability to maintain balance during movement, and this improved core stability has an important effect on improving the athlete's body control and stability during change of direction [8]. The present study found that significant gains in lower limb horizontal explosive strength (SLJ) also contributed to improved CoD performance, largely because the movement patterns of both SLJ and CoD involve horizontal displacements, and therefore gains in lower limb horizontal explosive strength could directly contribute to CoD performance [46]. Other studies have also supported the findings of the present study. For example, Hummami et al. [47]. 8-week PT training of soccer players showed that CoD performance was improved following PT training. As Coratella et al. [48] suggested the improvement of CoD performance may be attributed to the increase in braking ability generated by the enhanced eccentric workload associated with loaded training. In addition, Sheppard et al. [49] found that PT training could improve the eccentric strength of the thigh muscles, which is an important determinant of CoD performance during the deceleration phase of movement.

A key finding of the study was that DJ training demonstrated a significant dose effect in improving lower limb explosive strength, anaerobic power, and CoD in elite female wrestlers. Specifically, the study concludes that DJ training at heights of 40–60 cm is particularly effective for improving lower limb strength and anaerobic power in elite female wrestlers due to several factors as below: firstly, at 40–60 cm, the height range is optimal for activating fast-twitch muscle fibers, which are essential for explosive strength and power required in wrestling maneuvers. Greater engagement of these fibers leads to good neuromuscular adaptations beneficial for performance. Secondly, improvements seen in CMJ performance, which mirrors the explosive demands of elite wrestling, stem from the effective training stimulus provided by 40–60 cm DJ heights. Since CMJ uses similar biomechanics and muscle engagement as drop jumps, adaptations from DJ training in this range directly enhance CMJ performance. At the same time, DJ training at heights of 60–80 cm has a pronounced effect on enhancing CoD performance among elite female wrestlers, as shown in our study. The significant improvements can primarily be attributed to the optimal height range of 60–80 cm, which effectively promotes explosive and reactive strength through the SSC, facilitating greater recruitment of fast-twitch muscle fibers. This specific height serves as a powerful stimulus for plyometric jump training, leading to enhanced jump height that translates into improved motor skills, including sprinting and CoD speed [50]. Moreover, training within this height range enhances balance and neuromuscular coordination, resulting in quicker response times and more efficient movement patterns. The mechanics of drop jumps at 60–80 cm closely mimic the explosive actions required in wrestling, thus facilitating effective skill transfer. The inconsistencies found in the study regarding the optimal DJ height for improving lower limb explosive strength, anaerobic power, and CoD performance may be related to individual differences in participants, variations in flight and contact times during the execution of DJ movements, as well as familiarity with DJ training maneuvers and training experience [51]. This suggests that although DJ training has a positive effect on improving lower limb explosive strength, anaerobic power, and CoD capacity in elite female wrestlers, careful consideration needs to be given to adapting the intensity and depth of training to individual athlete differences. In particular, increasing or decreasing DJ height may have different effects on lower limb explosive power, anaerobic power, and CoD performance at different training cycles and stages of strength training development.

Although the study yielded notable results within the cohort of elite female wrestlers, several limitations should be acknowledged. Firstly, the participants in this study were limited to female athletes and did not involve male athletes, other age groups, or athletes of different skill levels. Therefore, the generalisability and applicability of the findings need to be further verified. Second, the sample size was relatively small, including only 40 athletes, which may limit the wide applicability and reliability of the findings. Future studies should expand the sample size to furnish more substantiated evidence. Moreover, considering the sport-specific attributes of wrestling, forthcoming inquiries should encompass a broader array of training interventions involving varied drop heights, with the aim of ascertaining the optimal drop heights conducive to wrestler performance. This will require more extensive and in-depth experimental studies in different groups of athletes to more accurately assess the effects of DJ training on athletes of different ages, genders, and skill levels. One notable limitation of the study is the absence of consideration for the potential impact of the participants' physical characteristics on the effects of DJ training. Height may affect the biomechanics of landing and jumping, potentially influencing measurements of explosive strength and power [52,53]. Future research should account for the impact of height to better analyze and interpret results, leading to more sophisticated conclusions about the effects of drop jump training on various athlete profiles. Additionally, jumping height and the height of participants should be given significant attention in future research, which should either control for height by standardizing participants or provide stratified analyses that account for height variability when evaluating the outcomes of drop jump training. In conclusion, this study provides valuable guidance on strength and conditioning training for elite female wrestlers, but a more detailed and comprehensive exploration of the direction and methodology of future research is still needed.

The findings of this study have important practical applications for physical coaches and practitioners in the training of elite female wrestlers. By providing an in-depth analysis of the effects of DJ training, the study provides valuable insights for physical coaches into how DJ training can be used to improve athletes' lower body explosiveness, anaerobic power, and CoD. These findings may serve as valuable insights for coaches in strategizing and structuring training programs with greater efficacy and specificity, particularly in the realm of enhancing lower body explosiveness, anaerobic power, and CoD.

5. Conclusions

These findings indicate that an 8-week DJ training program may enhance lower limb explosive strength, anaerobic power, and CoD performance among elite female wrestlers in China. Specifically, it was noted that training with DJ heights ranging from 40 to 60 cm led to more pronounced improvements in lower limb explosive strength and anaerobic power, while DJ heights between 60 and 80 cm were found to be more effective in enhancing CoD performance.

Disclosure statement

No potential conflict of interest was reported by the authors.

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CRediT authorship contribution statement

Yinchuan Bai: Writing – original draft, Project administration, Investigation, Funding acquisition, Conceptualization. **Zhanfei Zheng:** Data curation, Conceptualization. **Bingnan Gong:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Yupeng Shen:** Writing – review & editing, Methodology, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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