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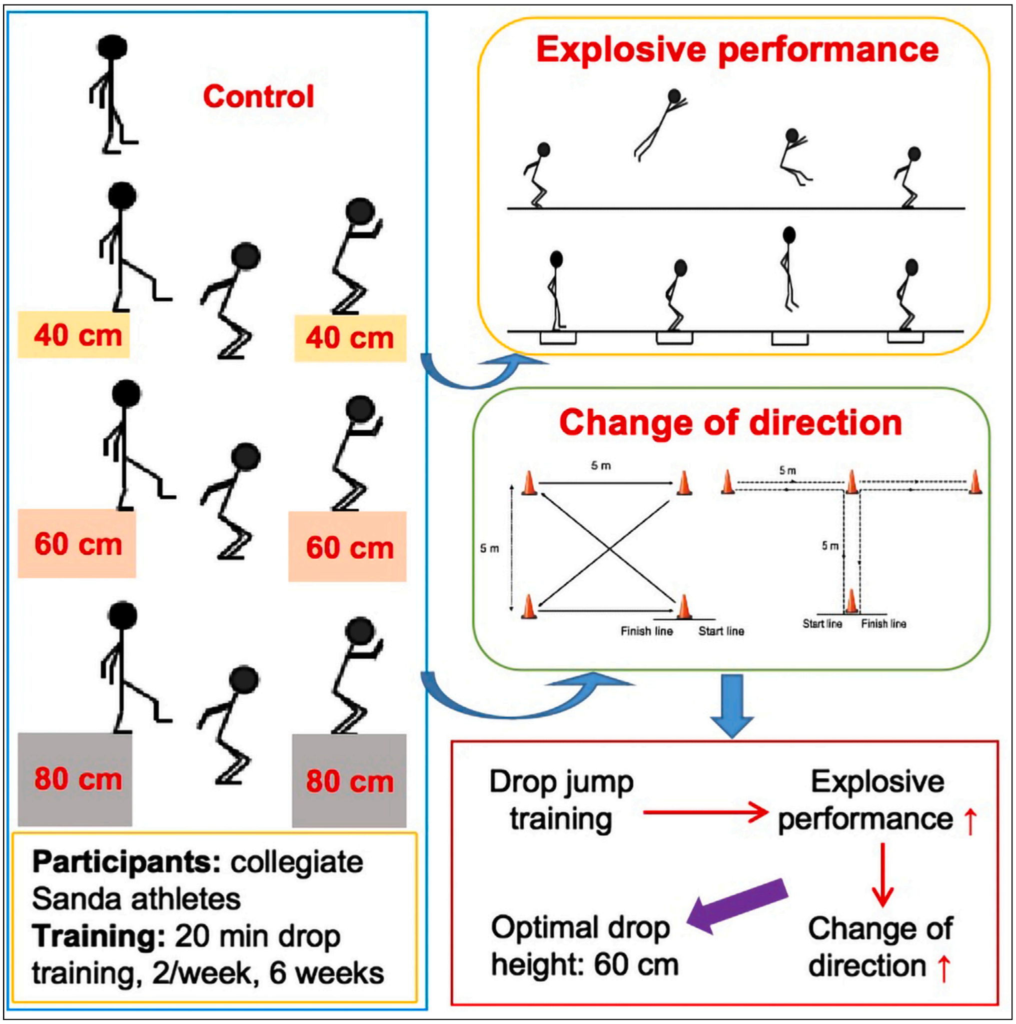

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Highlights

Drop jump training can improve explosive and change of direction performance

The optimal drop jump height is controversial

60 cm may be the optimal drop jump height for collegiate Sanda athletes

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Effects of different drop height training on lower limb explosive and change of direction performance in collegiate Sanda athletes

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SUMMARY

The purpose of the present study was to examine the effects of 6 weeks of 40-, 60-, or 80-cm drop jump (DJ) training on lower limb explosive and change of direction (CoD) performance in collegiate Sanda athletes. Repeated-measure ANOVA revealed that there was a significant group × time interaction for standing long jump test ($p = 0.006$), counter movement jump test ($p = 0.026$), Illinois agility test ($p = 0.003$), square test ($p = 0.018$), Nebraska test ($p = 0.027$), t test ($p = 0.032$), and hexagon test ($p = 0.012$) due to the best performance observed at post-test compared with pre-test for DJ60 (effect size = 0.89–2.89), and the improvement was higher than that of the other groups. These findings suggest that 6 weeks of DJ training could improve the lower limb explosive and CoD performance in collegiate Sanda athletes and that 60 cm may be the optimal drop height.

INTRODUCTION

Sanda, a popular form of Chinese boxing, is a highly confrontational sports competition, which was originally developed by the Chinese military based on combining traditional kung fu with modern combat fighting techniques.[1] The rapid development of Sanda has recently led to the establishment of the Chinese National Championships, the World Cup, and the World Championships.[2] Sanda footwork movement is mainly composed of running, jumping, straddling, quick start, emergency stop, and change of direction (CoD). For Sanda athletes, the key factors to success depend on strength, speed, and explosive performance, especially the ability to produce force quickly or at fast speeds. In the competition, athletes need to seize the transient opportunities and take timely offensive and defensive actions. With excellent CoD performance, Sanda athletes can reach the best offensive position and adjust the center of gravity, so that they can attack the opponents effectively in the fastest time.[3,4] Meanwhile, Sanda athletes can also quickly withdraw from the attack range of the opponents to effectively avoid opponents' attack.

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] strength,[8,10] speed,[11] running economy,[12] agility,[13,14] endurance performance,[8,9] 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, and jump heights.[17] 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.[18] 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.[19] 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,[20,21] but this might fail to reach the eccentric strength threshold of some athletes. In addition, Decker et al.[22] 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.[23] 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

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Table 1. Descriptive statistics of lower limb explosive performance test results before and after the 6-week training intervention

	Controls (n = 9)			DJ40 (n = 9)			DJ60 (n = 9)			DJ80 (n = 9)			Group × time	
	Pre	Post	ES	Pre	Post	ES	Pre	Post	ES	Pre	Post	ES	p	Partial η^2
SLJ (m)	2.67 ± 0.11	2.68 ± 0.10	0.12	2.68 ± 0.11	2.73 ± 0.09[a]	0.56	2.67 ± 0.11	2.76 ± 0.11[b]	0.89	2.69 ± 0.10	2.75 ± 0.08[c]	0.72	0.006	0.316
CMJ (m)	0.46 ± 0.06	0.46 ± 0.05	0.10	0.46 ± 0.05	0.48 ± 0.05	0.36	0.45 ± 0.04	0.50 ± 0.04[b]	1.17	0.47 ± 0.04	0.51 ± 0.03[c]	1.16	0.026	0.248

SLJ, standing long jump; CMJ, counter movement jump; ES, effect size; DJ, drop jump.
[a]Significantly different between pre-training and post-training in DJ40, $p < 0.01$.
[b]Significantly different between pre-training and post-training in DJ60, $p < 0.01$.
[c]Significantly different between pre-training and post-training in DJ80, $p < 0.01$.

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.[24] reported that compared with 20-, 40-, 60-, and 100-cm drop heights, the best gymnasts (finalists at World Championship) obtained their best performance at 80-cm drop.

Although previous studies have reported the characteristics of lower limb muscle strength of Sanda athletes,[2,3] to our knowledge there are no studies addressing lower limb explosive and CoD performance in Sanda athletes. Considering that different DJ heights have different effects on lower limb explosive and CoD performance, the aim of the present study was to examine the effects of 6 weeks of DJ executed from 40-, 60-, and 80-cm height boxes on lower limb explosive and CoD performance in collegiate Sanda athletes, thus holding promise as an effective strength and conditioning training strategy for collegiate Sanda athletes.

RESULTS

Effects of DJ training on lower limb explosive performance

To determine whether DJ training had effects on the lower limb explosive performance in collegiate Sanda athletes, standing long jump (SLJ) and counter movement jump (CMJ) were conducted before and after the 6-week training intervention. Table 1 presents the descriptive statistics of all lower limb explosive performance tests, results of repeated ANOVA for pre-and post-training fitness testing, and corresponding effect sizes (ESs). No statistically significant differences between groups were found at baseline for all test measures.

For control group, there was no significant difference in SLJ test ($p = 0.419$) and CMJ test ($p = 0.630$). For experimental groups, training resulted in statistically significant improvement in SLJ test (DJ40: $p = 0.002$, partial $\eta^2 = 0.260$; DJ60: $p = 0.000$, partial $\eta^2 = 0.544$; DJ80: $p = 0.000$, partial $\eta^2 = 0.352$) and CMJ test (DJ60: $p = 0.000$, partial $\eta^2 = 0.387$; DJ80: $p = 0.001$, partial $\eta^2 = 0.312$) but DJ60 showed the highest ESs in both SLJ test and CMJ tests. Significant group × time interaction effects were shown among groups for SLJ test ($F = 4.930$, $p = 0.006$) and CMJ test ($F = 3.520$, $p = 0.026$), indicating a significantly greater improvement in the lower limb explosive performance after the DJ60 intervention when compared with the other groups.

Effects of DJ training on the CoD performance

Since the improved lower limb explosive performance contributes to CoD performance, we next examined the CoD performance in collegiate Sanda athletes with the Illinois agility test, square test, Nebraska test, t test, and hexagon test.

As shown in Table 2, for the control group, there was no significant difference in Illinois agility test ($p = 0.497$), square test ($p = 0.880$), Nebraska test ($p = 0.200$), t test ($p = 0.484$), and hexagon test ($p = 0.823$). For experimental groups, training resulted in statistically significant improvement in Illinois agility test (DJ40: $p = 0.043$, partial $\eta^2 = 0.122$; DJ60: $p = 0.000$, partial $\eta^2 = 0.550$; DJ80: $p = 0.002$, partial $\eta^2 = 0.266$), square test (DJ40: $p = 0.043$, partial $\eta^2 = 0.122$; DJ60: $p = 0.000$, partial $\eta^2 = 0.427$; DJ80: $p = 0.036$, partial $\eta^2 = 0.131$), Nebraska test (DJ40: $p = 0.001$, partial $\eta^2 = 0.287$; DJ60: $p = 0.000$, partial $\eta^2 = 0.487$; DJ80: $p = 0.000$, partial $\eta^2 = 0.430$), t test (DJ40: $p = 0.010$, partial $\eta^2 = 0.188$; DJ60: $p = 0.000$, partial $\eta^2 = 0.445$; DJ80: $p = 0.001$, partial $\eta^2 = 0.292$), and hexagon test (DJ40: $p = 0.007$, partial $\eta^2 = 0.204$; DJ60: $p = 0.000$, partial $\eta^2 = 0.456$; DJ80: $p = 0.001$, partial $\eta^2 = 0.287$), but DJ60 showed the highest ESs in Illinois agility test, square test, Nebraska test, t test, and hexagon test. Significant group × time interaction effects were shown among groups for Illinois agility test ($F = 5.623$, $p = 0.003$), square test ($F = 3.876$, $p = 0.018$), Nebraska test ($F = 3.478$, $p = 0.027$), t test ($F = 3.324$, $p = 0.032$), and hexagon test ($F = 4.274$, $p = 0.012$), indicating a significantly greater improvement in the CoD performance after the DJ60 intervention when compared with the other groups.

DISCUSSION

Very few studies have focused on the performance of Sanda athletes. To the best of our knowledge, this is the first study to investigate the effects of DJ training on lower limb explosive and CoD performance in collegiate Sanda athletes to explore the potential effects of different DJ heights. We found improved lower limb explosive and CoD performance in experimental groups after a 6-week training. However, drop height had a significant effect on the improvements.

Table 2. Descriptive statistics of CoD test results before and after the 6-week training intervention

	Controls (n = 9)			DJ40 (n = 9)			DJ60 (n = 9)			DJ80 (n = 9)			Group × time	
	Pre	Post	ES	Pre	Post	ES	Pre	Post	ES	Pre	Post	ES	p	Partial η^2
IAT (s)	16.27 ± 0.68	16.19 ± 0.67	0.13	16.24 ± 0.43	15.98 ± 0.33[a]	0.71	16.37 ± 0.63	15.62 ± 0.50[c]	1.42	16.44 ± 0.62	16.02 ± 0.56[e]	0.74	0.003	0.345
ST (s)	7.91 ± 0.60	7.89 ± 0.55	0.04	7.95 ± 0.55	7.65 ± 0.40[a]	0.66	7.90 ± 0.33	7.21 ± 0.68[c]	1.37	7.92 ± 0.49	7.62 ± 0.47[d]	0.67	0.018	0.267
NT (s)	12.12 ± 0.58	11.71 ± 0.59	0.74	11.80 ± 0.63	10.68 ± 0.71[b]	1.78	12.01 ± 0.45	10.29 ± 0.78[c]	2.89	11.74 ± 0.60	10.21 ± 1.05[e]	1.91	0.027	0.246
TT (s)	9.30 ± 0.61	9.20 ± 0.58	0.17	9.27 ± 0.63	8.90 ± 0.55[a]	0.67	9.30 ± 0.45	8.61 ± 0.43[c]	1.68	9.34 ± 0.63	8.84 ± 0.45[e]	0.97	0.032	0.238
HT (s)	13.66 ± 1.77	13.54 ± 1.76	0.07	13.75 ± 2.03	12.31 ± 1.96[b]	0.77	13.75 ± 2.53	11.15 ± 1.49[c]	1.54	13.65 ± 1.17	11.84 ± 1.31[e]	1.33	0.012	0.286

IAT, Illinois agility test; ST, square test; NT, Nebraska test; TT, t test; HT, hexagon test; ES, effect size; DJ, drop jump; CoD, change of direction.
[a]Significantly different between pre-training and post-training in DJ40, $p < 0.05$.
[b]Significantly different between pre-training and post-training in DJ40, $p < 0.01$.
[c]Significantly different between pre-training and post-training in DJ60, $p < 0.01$.
[d]Significantly different between pre-training and post-training in DJ80, $p < 0.05$.
[e]Significantly different between pre-training and post-training in DJ80, $p < 0.01$.

Effects of drop height on lower limb explosive performance

Among the various types of PT, DJ represents one of the most frequently applied jump training aimed at improving lower limb explosive performance. Similar to taekwondo, judo, and wrestling, Sanda athletes need to have explosive speed and strength besides absolute strength.

Our results showed that neither SLJ nor CMJ test was significantly different in the control group, whereas 6 weeks of DJ training significantly increased the SLJ in the DJ40, DJ60, and DJ80 and significantly increased the CMJ in the DJ60 and DJ80, which were in agreement with previous studies, showing that 6 weeks of PT had positive effects on the sprint and jump performance in football players.[11,25] Therefore, we might conclude that 6 weeks of 40-, 60-, and 80-cm DJ training could contribute to the improvement of the horizontal explosive performance and 60- and 80-cm DJ training could contribute to the improvement of the vertical explosive performance in collegiate Sanda athletes.

To implement a safe and effective DJ program, several methodological aspects must be considered, such as the intensity, the volume, the landing surfaces, the recovery time, and the drop heights.[26,27] Considering there is controversy about the optimal drop height, the study also compared the effects of different drop heights on the CoD performance of collegiate Sanda athletes. The present results showed that DJ60 had the highest ESs in both SLJ and CMJ tests and there was a significant intervention effect (group × time) on SLJ and CMJ tests, which indicated a significantly greater improvement in the lower limb explosive performance after the DJ60 intervention when compared with the other groups. Compared with the DJ40, 60-cm drop height resulted in a higher intensity, which contributed to a larger improvement in both lower limb explosive performance. Because of the great association between jumping performance and segmental coordination, skill and technique and training specificity are important factors to take into account, especially when DJ is performed.[28] As reported by Marina et al.,[24] higher intensities may lead to decreased flight time and increased contact time, which in turn resulted in lower explosive and CoD performance. In addition, Wilson et al.[19] reported that 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. Therefore, in this study, 80-cm drop height resulted in a higher intensity than 60 cm, which may have been too high given the training experience of participants.

Effects of drop height on CoD performance

CoD performance has been shown to be one of the key determinants in many sports.[29–31] Recently, Hummami et al.[32] investigated the effects of 8 weeks of PT in soccer players, and their results showed that the CoD performance of soccer players was enhanced after PT. As Coratella et al.[33] proposed the improvement of CoD performance may be contributed to the increase of braking ability generated by the enhanced eccentric workload associated with loaded training. In addition, Sheppard et al.[34] suggested that PT could improve the eccentric strength of the thigh muscles, which is an important determinant of CoD performance during the deceleration phase of movement.

In the present study, for the control group, there was no significant difference in Illinois agility test, square test, Nebraska test, t test, and hexagon test. However, 6 weeks of DJ training significantly improved the Illinois agility test, square test, Nebraska test, t test, and hexagon test in DJ40, DJ60, and DJ80. In addition, significant group × time interaction effects were shown among groups, and DJ60 had the highest ESs, which indicated a significantly greater improvement in the CoD performance after the DJ60 intervention when compared with the other groups.

As mentioned above, 6 weeks of DJ training improved the horizontal explosive performance in DJ40, DJ60, and DJ80 and improved the vertical explosive performance in DJ60 and DJ80. Interestingly, in DJ40, the improvement in CoD performance was not parallel to the improvement in vertical explosive performance. As the CoD ability was the displacement in the horizontal direction, which was similar to the displacement mode of SLJ. Therefore, the improvement of the horizontal explosive performance contributed to the improvement of CoD performance. Taken together, 6 weeks of 40-, 60-, and 80-cm DJ training facilitated CoD performance by improving the horizontal explosive performance in collegiate Sanda athletes, which was consistent with previous studies, showing that the horizontal explosive performance played an important role in the improvement of CoD performance.[35,36]

Although the DJ60 training induced the greatest explosive and CoD performance in our study, is 60 cm the optimal drop height for collegiate Sanda athletes to improve the lower limb explosive and CoD performance? The answer was uncertain, and we were unable to determine whether additional increases or decreases in drop height during DJ training would further improve lower limb explosive and CoD performance. Further investigations on more different drop heights were needed. Therefore, based on our current findings, compared with 40 cm and 80 cm, 60 cm may be a more effective drop height for collegiate Sanda athletes to improve lower limb explosive and CoD performance.

Limitations of the study

This study comes with a few limitations that should be taken for consideration. First, the sample size of 36 people is relatively small as Sanda is a relatively low-profile sport with a limited number of athletes participating in the sport; future studies with a larger sample size on other cohorts are thus highly demanded. Second, our observations to date are primarily applicable to collegiate Sanda athletes at a specific level of competition and there is a need to extend observations to cover female athletes, other age groups, and other skill levels. Finally, further investigations on more different drop heights were needed to determine the optimal drop height for collegiate Sanda athletes to improve the lower limb explosive and CoD performance. Researchers should be, therefore, cautious when interpreting and generalizing the current findings.

Conclusions

Our findings suggest that 6 weeks of DJ training could improve the lower limb explosive and CoD performance in collegiate Sanda athletes and that 60 cm may be the optimal drop height.

Practical applications

This study provides a valuable insight for strength and conditioning coaches and practitioners interested in DJ training for collegiate Sanda athletes. Our outcomes could help coaches and practitioners to better structure their training programs with respect to the types of training used. Future investigations are required to examine DJ-induced neuromuscular mechanisms responsible for improvements in lower limb explosive and CoD performance in collegiate Sanda athletes. In addition, future investigations on more different drop heights are needed.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2023.107972.

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AUTHOR CONTRIBUTIONS

Conceptualization, G.L. and L.Y.; investigation, G.L., W.W, K.Z., S.Z., Z.C., Y.L., and X.H.; formal analysis, G.L., W.W, and X.H.; writing – original draft, G.L. and L.Y.; writing – review & editing, G.L., W.W, X.H., and L.Y.

DECLARATION OF INTERESTS

No potential conflict of interest was reported by the author(s).

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Software and algorithms		
SPSS 25.0	International Business Machines Corporation (IBM)	https://www.ibm.com/spss?mhsrc=ibmsearch_a&mhq=spss%20online
Other		
EZEJUMP vertical jump testing system	Swift Performance	https://store.swiftperformance.com

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources and reagents should be directed to and will be fulfilled by the lead contact, Laikang Yu (yulaikang@126.com).

Materials availability

This study did not generate new unique reagents.

Data and code availability

Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

EXPERIMENTAL MODEL AND STUDY PARTICIPANT DETAILS

A total of 36 healthy collegiate Sanda athletes (male, age: 18.72 ± 0.78 y) were recruited for this study. 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. Exclusion criteria were neurological disorders and/or injuries/diseases of the musculoskeletal system. The participants were randomly allocated into 4 groups: Con, DJ40, DJ60, and DJ80. Descriptive characteristics for the study subjects can be viewed in below table. There were no statistically significant differences among the groups in these personal characteristics.

Participants' physical characteristics

	Controls (n = 9)	DJ40 (n = 9)	DJ60 (n = 9)	DJ80 (n = 9)
Age (years)	18.89 ± 0.78	18.56 ± 0.88	18.78 ± 0.67	18.67 ± 0.87
Height (m)	1.78 ± 0.03	1.77 ± 0.05	1.78 ± 0.05	1.79 ± 0.02
Weight (kg)	72.06 ± 2.77	71.63 ± 3.13	71.19 ± 2.71	72.91 ± 2.19
Training experience (years)	3.22 ± 0.67	3.28 ± 0.71	3.22 ± 0.51	3.11 ± 0.49

Before data collection, the participants were informed about the benefits and possible risks associated with the study. The study protocol was approved by the Ethics Committee of Beijing Sport University (Approval number: 2020163H), and all procedures were carried out in accordance with the recommendations of the Declaration of Helsinki. All participants gave written informed consent in accordance with the Declaration of Helsinki.

METHOD DETAILS

Study design

This study was conducted to investigate the effects of 6 weeks of DJ from different jump heights on lower limb explosive and CoD performance in collegiate Sanda athletes. According to previous studies, different DJ heights have different effects on lower limb explosive and CoD performance, and the commonly used DJ heights are 20 cm, 40 cm, 60 cm, 80 cm, and 100 cm.[20–24] Therefore, in this study, participants were randomly allocated into 4 groups as follows: control group (Con), 40-cm DJ group (DJ40), 60-cm DJ group (DJ60), and 80-cm DJ group (DJ80). Participants in DJ40, DJ60, and DJ80 received 40-cm DJ training, 60-cm DJ training, and 80-cm DJ training for a period of 6 weeks, respectively. The control group was used to account for any non-training-related changes in performance that may have occurred over the course of the study. Before and after a 6-week training period, participants were assessed by several tests, which were performed by the same investigators who were blinded to the intervention.

Training program

As shown in below table, all DJ training sessions lasted about 20 minutes and were performed after a 10-minute warm-up. For week 1 and week 2, all DJ training sessions included 3 sets of 10 repetitions of DJ from either 40-, 60-, or 80-cm height boxes (i.e., 30 contacts), with 15 and 120 seconds of rest between repetitions and sets, respectively. As participants improved, the number of repetitions increased to 15 (i.e., 45 contacts) for week 3 and week 4 and to 20 (i.e., 60 contacts) for week 5 and week 6. Participants were instructed to jump to their maximal height with minimal contact time to maximize reactive strength. At the end of the training session, effective static stretching techniques were performed for 10-minute cool-down. The training frequency was twice a week, with a minimum interval of 48 hours, on Tuesday and Friday.

Training schedule of DJ40, DJ60, and DJ80 protocols

Week	Group	Jump height (cm)	Jumps/set	Sets	Rest between repetitions (s)	Rest between sets (s)
1–2	DJ40	40	10	3	15	120
	DJ60	60	10	3	15	120
	DJ80	80	10	3	15	120
3–4	DJ40	40	15	3	15	120
	DJ60	60	15	3	15	120
	DJ80	80	15	3	15	120
5–6	DJ40	40	20	3	15	120
	DJ60	60	20	3	15	120
	DJ80	80	20	3	15	120

Based on previous studies, we chose the standing long jump (SLJ) and countermovement jump (CMJ) to test the effect of DJ on lower limb explosive,[6,7,15,16,20,21] and the Illinois agility test, square test, Nebraska test, T-Test, and hexagon test to test the effect of DJ on CoD performance in collegiate Sanda athletes.[13–16] All tests were done in one day, with SLJ, CMJ, Nebraska test, and T-Test in the morning and hexagon test, square test, and Illinois agility test in the afternoon. Prior to testing, participants underwent familiarization training to minimize the impact of learning on testing.

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.[37] previously described: (1) shake the arm sufficiently and recoil, (2) jump with the knees tightly bent, and (3) 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-second was allowed between Trails and the best out of three Trails was retained for further analysis.

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-second was allowed between Trails and the best out of three Trails was retained for further analysis.

Illinois agility test

The Illinois agility test was administered using a version standardized from a previous study.[38] The Illinois agility test course was marked by cones, with four corner cones positioned as a 10 m × 5 m rectangle and four center cones spaced 3 m apart (see Figure S1A). The test began with the participant lying prone on the floor behind the starting line with head facing forward and arms at his side. On the "start" command, the participant stood up, ran or quickly moved forward to the first cone in the far line. Participants were required to cross the cones. The participant turned around and moved to the first center cone, and then weaved up and back through the four center cones followed by a fast run to the second cone on the far line as quick as possible. Again, participants were required to cross the cones. Finally, the participant turned around and ran across the finish line as fast as he could. The time to complete each Trail was recorded and the best out of two Trails was retained for further analysis.

Square test

The square test course was marked by cones, with four corner cones positioned as a 5 m × 5 m square (see Figure S1B). The test began with the participant standing on the side of the second cone on the near line. On the "start" command, the participant (1) ran and moved forward to the first cone on the far line as quickly as possible, (2) sidestepped right 5 m to the second cone on the far line, (3) moved backward to the first cone on the near line, and finally ran as fast as possibly to cross the finish line. The time to complete each Trail was recorded and the best out of two Trails was retained for further analysis.

Nebraska test

The Nebraska test began with the participant standing upright on the side of the second cone on the near line with head facing forward (see Figure S1C). On the "start" command, the participant (1) ran and moved forward to the second cone on the far line as quickly as possible, (2) sidestepped to the center cone on the far line with head facing outside, (3) sidestepped to the first cone on the far line with head facing inside, (4) moved backward to the first cone on the near line, (5) ran and moved forward to cross the center cone on the near line, and finally ran as fast as possibly to cross the finish line. The time to complete each Trail was recorded and the best out of two Trails was retained for further analysis.

T-test

The T-Test was administered using a version standardized from a previous study.[38] The T-Test course was marked by cones, with four cones positioned as "T" (see Figure S1D). The test began with the participant standing upright on the side of the base cone with head facing forward. On the "start" command, the participant (1) ran and moved forward to the center cone on the far line as quickly as possible, (2) sidestepped left 5 m to the first cone on the far line, (3) sidestepped right 10 m to the third cone on the far line, (4) sidestepped left 5 m to the center cone on the far line, and finally moved backward to cross the finish line as fast as possible. The time to complete each Trail was recorded and the best out of two Trails was retained for further analysis.

Hexagon test

The hexagon test course was a hexagon, and the length of each side was 60 cm (see Figure S1E). The test began with the participant standing in the middle of the hexagon in an upright stance and facing forward. The participant started the test by double-leg hopping from the center of the hexagon across one side of the hexagon and back to the center, which was performed in a clockwise direction until each side of the hexagon was crossed and the entire hexagon was traversed a total of three times. The time to complete each Trail was recorded and the best out of two Trails was retained for further analysis.

QUANTIFICATION AND STATISTICAL ANALYSIS

Data were presented as mean $\pm$ standard deviation (SD). Normality was checked using the Shapiro-Wilk test. Training-related effects were assessed by two-way repeated-measure ANOVA (group × time) on SLJ, CMJ, Illinois agility test, square test, Nebraska test, T-Test, and hexagon test, with the Greenhouse-Geisser adjustment was applied. Partial η^2 was used as the effect size (ES) estimation with its strength being interpreted as the following: < 0.06 as small, < 0.14 as moderate, and ≥ 0.14 as large.[39] When a significant effect was found, Bonferonni *post-hoc* correction was performed to identify pairwise differences. The absolute value of each test result was used to calculate the ES for the within- and between- group comparisons, represented as Cohen's *d*. It was interpreted according to the following thresholds: < 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.[40] Experimental data were processed by IBM SPSS statistical software package (version 25.0, IBM, Chicago, IL, USA). The level of significance was set at $p < 0.05$ for all tests.