



Identifying the Effects of Unilateral and Bilateral Complex Training on the Maximum Strength, Explosive Power, and Changing Direction Ability of Volleyball Players

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Abstract

Background. Unilateral and bilateral complex trainings are techniques that combine various exercises focused on developing different muscle groups and physical qualities, such as strength, power, speed, and balance. Understanding the most effective training strategy is essential for optimizing volleyball-specific physical performance.

Objectives. This study aimed to compare the effects of unilateral and bilateral complex training on lower-limb performance, specifically maximum strength, explosive power, and change-of-direction ability, in male collegiate volleyball players, and to evaluate these effects within this specific group.

Materials and Methods. A total of 68 male volleyball players aged 18-26 years from four universities in Shanghai were randomly assigned to unilateral (n = 34) or bilateral (n = 34) training groups. Both groups underwent 8 weeks of complex training programs designed based on expert input. Performance outcomes included 1RM squat, isometric mid-thigh pull (IMTP), countermovement jump (CMJ), drop jump (DJ), 5m and 10m sprints, and agility tests. Data were analyzed using paired and independent sample t-tests and Cohen's d for effect sizes.

Results. Both training protocols significantly improved all performance indicators ($p < 0.05$ or $p < 0.01$). The unilateral group showed substantially greater enhancements in unilateral IMTP, single-leg CMJ and DJ, and short-distance sprint times. The bilateral group had better bilateral CMJ gains and slightly higher ball speed, though only bilateral CMJ reached statistical significance. No marked difference was found in change-of-direction ability, though unilateral training yielded slightly greater progress.

Conclusions. The findings indicate that both unilateral and bilateral complex training are effective for enhancing lower-limb performance. However, unilateral training may be more beneficial for improving single-leg power and sprinting, while bilateral training better supports bilateral explosive strength and volleyball-specific skills.

Keywords: unilateral training, bilateral training, lower-limb performance, explosive power, sprint speed, collegiate volleyball players.

Introduction

Volleyball, as a high-intensity intermittent sport, places high demands on athletes' maximum strength, explosive power, and ability to change direction, all of which are crucial to performance. The "Outline for Building a Sports Strong Country" (State Council Bulletin of the People's Republic of China, 2019) and the "Notice on Further Strengthening Basic Physical Training" (General Administration of Sport

of China, 2020), highlight the importance of developing scientific, systematic training systems and improving athletes' physical fitness as a foundation for overall competitive ability. Physical fitness significantly influences technical, psychological, and cognitive performance, with strength and agility being core components. Explosive power defined as a rapid accumulation of force and directional mobility referring to the athlete's ability to decelerate, change direction, and accelerate again are essential in volleyball due to its fast-paced, reactive nature. Players often execute powerful and quick actions such as passing, spiking, and blocking within seconds. The modern evolution of volleyball, emphasizing

strength-based techniques and rapid movement patterns, further underscores the importance of leg explosive power and agility. As noted by Sheppard (2006), explosive leg power enhances directional changes, a view supported by Ben Abdelkrim (2010) and Çakır, Mehmet, and Esin Ergin (2022), who emphasize that fast, multi-directional movements are foundational to effective performance in both offensive and defensive actions. Therefore, developing explosive strength and change-of-direction ability is critical for improving volleyball athletes' competitive level and overall game performance.

Current volleyball agility training mainly emphasizes multi-directional movement (Chuang, 2022; Born, 2016), this study found that drop jump training from a height of 60 cm was the most effective for improving lower limb explosive power and change of direction performance in collegiate Sanda athletes. However, the researchers noted that further studies are necessary to confirm the optimal drop height for this type of training (Li et al., 2023). Research indicates that enhanced lower limb explosiveness improves the body's ability to overcome resistance during rapid directional changes, thereby boosting agility (Kovaleski, 2001; Peterson, 2006; Barnes, 2007). As a result, improving lower limb strength, explosive power, and agility in volleyball athletes has become a key training objective. Traditional methods such as reinforcement and resistance training have shown limited effectiveness due to various constraints. In contrast, complex training originating in the 1970s and combining resistance with biomechanically similar plyometric exercises has emerged as a more scientific and efficient method (Fukunaga, 1997; Weber, 2006; Hao, 2019). By leveraging post-activation potentiation, complex training has proven beneficial in enhancing explosive strength, initially in long jumpers and now in a wide range of sports (Liu, 2021). Compared to standalone resistance training, it offers greater improvements in rapid strength development, performance enhancement, reduced training time, and lower injury risk. However, inconsistencies in experimental results highlight the ongoing need to refine complex training protocols to maximize their effectiveness.

Previous studies on complex training have explored both unilateral and bilateral approaches, where unilateral complex training involves single-leg exercises (e.g., lunge squats, single-leg jumps) and bilateral complex training uses both legs simultaneously (e.g., squats, frog jumps). Research by Young (2006) indicated that bilateral vertical training exercises produce weaker effects in elite athletes, with low transfer to actual athletic performance despite improving maximum strength. Similarly, Cronin et al. (2007) found that back squat strength transfers poorly to sprint performance, especially in high-level athletes. In contrast, unilateral resistance training has been shown to enhance strength and physical stability, with studies suggesting it aligns better with sport-specific movement patterns and reduces injury risk (Jones et al., 2012). Unilateral training has also been associated with improved agility, sprinting, and jumping abilities (Speirs et al., 2016; McCurdy et al., 2010; Bogdanis et al., 2019). One explanation for its effectiveness is the bilateral force deficit phenomenon, where the total force generated unilaterally can exceed that of bilateral training. Despite these findings, there is still limited research on the effects of unilateral complex training, especially in volleyball,

and existing studies often lack in-depth comparisons of unilateral and bilateral approaches in complex training settings. Therefore, further research is needed to determine the most effective method for improving maximum strength and explosive power in volleyball players.

Based on the above, this study aims to systematically compare the effects of unilateral and bilateral complex training on the maximum strength, explosive power, and change-of-direction ability of volleyball players, with the goal of clarifying the mechanisms and differences in training outcomes between these two modes. Through scientifically designed training programs, the research seeks to evaluate the effectiveness of each approach in enhancing lower limb performance and provide empirical evidence to support coaches in creating individualized training plans. The study not only contributes to the theoretical framework of complex training and fosters innovation in training methodologies but also offers practical, evidence-based guidance for improving volleyball athletes' performance. Additionally, the findings may serve as a reference for training practices in other team ball sports. The main objectives are: (1) to compare the effects of unilateral and bilateral complex training on volleyball players' maximum strength, explosive power, and change-of-direction ability, and (2) to evaluate these effects within a specific group of volleyball players.

Material and Methods

This study was experimental research, aiming to compare the effects of unilateral and bilateral complex training of the lower limbs on developing the maximum strength, explosive power, and changing direction ability of volleyball players' lower limbs. During the experiment, two different training programs, namely unilateral complex training and bilateral complex training, were adopted. The training effects of the two training programs were measured by comparing the pre-test and post-test results of various indicators of the maximum strength, explosive power, and changing direction ability of the lower limbs.

Participants

This study employed an experimental design and involved male college volleyball players aged 18 to 26 years. A total of 68 athletes from two universities in Shanghai. The mean age of participants in the EG was 20.88 ± 1.43 years, with an average height of 184.71 ± 7.44 cm, weight of 80.20 ± 12.19 kg, and body fat percentage (BFP) of 15.76 ± 3.48 %. For the CG, the mean age was 20.76 ± 1.30 years, with an average height of 185.53 ± 7.77 cm, weight of 80.93 ± 10.96 kg, and BFP of 15.01 ± 3.96 %. These results indicate that the two groups were comparable in terms of basic physical characteristics at baseline, with no significant differences observed between the groups. The basic characteristics of volleyball players are shown in Table 1.

Participants were included in the study if they met the following criteria: (1) voluntarily provided informed consent, (2) had a minimum of 2 years of volleyball training experience, (3) were between 18 and 26 years old, (4) had no major sports injuries in the past 3 months, and (5) were available to attend all training sessions throughout the intervention period. Exclusion criteria included: (1) any

Table 1. Basic Characteristics of Volleyball Players in the EG and CG Groups

Group	Characteristics	Mean	SD
Experimental Group (EG)	Age	20.88	1.43
	Height (cm)	184.71	7.44
	Weight (kg)	80.20	12.19
	BFP (%)	15.76	3.48
Control Group (CG)	Age	20.76	1.30
	Height (cm)	185.53	7.77
	Weight (kg)	80.93	10.96
	BFP (%)	15.01	3.96

recent injury without full recovery, (2) current use of medication due to illness, (3) scheduling conflicts that would prevent full participation, or (4) a lack of commitment to completing the study.

All procedures involving human participants were conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments. Ethical approval for this study was obtained from Mahasarakham University (Certificate No. 655-533/2024) and Shanghai University (Certificate No. ECSHU 2024-076).

Data Collection Procedure

Participants were selected using stratified purposive sampling to include both high-level and ordinary collegiate volleyball athletes. The sampling process included the following steps:

1. Identification of eligible players based on inclusion/exclusion criteria.
2. Use of G*Power 3.1.9.7 software to determine the required sample size ($\alpha = 0.05$, power = 0.80, effect size = 0.8), resulting in 27 per group.

Table 2. Comparison of the data before and after the experiment in CG (n = 34)

Variable		Pre	Post	t	p - value
		Mean (SD)	Mean (SD)		
Maximum strength	1RM Squat	115.18 ± 18.58	138.29 ± 23.85	-5.211	0.000**
	Isometric Mid-Thigh Pull (Bilateral)	2235.84 ± 328.93	2559.44 ± 308.11	-4.844	0.000**
	Isometric Mid-Thigh Pull (Left side)	1977.80 ± 285.94	2134.09 ± 223.99	-3.405	0.002**
	Isometric Mid-Thigh Pull (Right-side)	1958.86 ± 241.95	2124.65 ± 170.66	-3.812	0.001**
Explosive power	CMJ, (cm) (Left side)	20.70 ± 4.25	21.92 ± 3.87	-3.496	0.001**
	CMJ, (cm) (Right-side)	20.20 ± 3.94	21.28 ± 3.41	-4.037	0.000**
	CMJ, (cm) (Bilateral)	43.01 ± 6.02	47.62 ± 4.65	-6.241	0.000**
	DJ, (m/s) (Left-side)	0.72 ± 0.17	0.75 ± 0.14	-2.245	0.032*
	DJ, (m/s) (Right-side)	0.70 ± 0.16	0.74 ± 0.12	-2.460	0.019*
	DJ, (m/s) (Bilateral)	1.72 ± 0.27	1.82 ± 0.35	-3.349	0.002**
	5-meter sprint, (s)	1.02 ± 0.06	0.99 ± 0.08	3.238	0.003**
	10-meter sprint, (s)	1.74 ± 0.09	1.68 ± 0.09	5.630	0.000**
	Jump-spiked ball speed, (m/s)	18.55 ± 3.35	20.60 ± 3.00	-4.558	0.000**
Jump-served ball speed, (m/s)	19.68 ± 3.34	21.42 ± 2.59	-3.326	0.001**	
Changing direction ability	180° Change of Direction Speed(s)	1.15 ± 0.11	1.13 ± 0.14	2.286	0.029*

Note: CG: Control group (Bilateral Complex Training Group); * p<0.05 ** p<0.01

3. Adjusting for a 20% dropout rate, the final sample size was increased to 34 per group, totaling 68 participants.
4. Random group assignment was performed using the lottery method by school for practical convenience.
5. Final consent was obtained via face-to-face communication and written clarification documents.

Instruments

The training interventions were designed using expert interviews and a questionnaire survey. Interviews involved 9 sports training professionals, while an additional 12 experts completed structured questionnaires. Performance measurements included:

- Maximum Strength of the lower limbs.
- Explosive Power (e.g., vertical jump).
- Changing Direction Ability (e.g., agility tests).

The precise measurement protocols and tools (e.g., dynamometers, timing gates, force plates) will be described in the subsequent section of the article.

Statistical Analysis

Data were analyzed using SPSS (Version 24). Descriptive statistics (mean, SD) were calculated for all variables. Inferential analyses included:

1. Independent sample t-tests for between-group comparisons.
2. Paired t-tests for within-group pre- and post-test comparisons.
3. Effect sizes (Cohen's d) to interpret the magnitude of the training effects.

Statistical significance was set at $p < 0.05$.

Results

After the experiment, both the control group and the experimental group showed statistically significant

Table 3. Comparison of the data before and after the experiment in EG (n = 34)

	Variable	Pre	Post	t	p - value
		Mean (SD)	Mean (SD)		
Maximum strength	1RM Squat	110.62 ± 20.22	128.59 ± 23.42	-4.185	0.000**
	Isometric Mid-Thigh Pull (Bilateral)	2144.11 ± 295.76	2421.26 ± 346.36	-3.899	0.000**
	Isometric Mid-Thigh Pull (Left - side)	1911.81 ± 244.76	2178.79 ± 221.77	-5.103	0.000**
	Isometric Mid-Thigh Pull (Right - side)	1893.08 ± 232.25	2177.44 ± 251.07	-6.657	0.000**
Explosive power	CMJ, (cm) (Left - side)	20.71 ± 4.45	23.43 ± 4.93	-6.618	0.000**
	CMJ, (cm) (Right - side)	20.04 ± 3.83	23.05 ± 3.49	-7.366	0.000**
	CMJ, (cm) (Bilateral)	43.71 ± 5.47	45.44 ± 6.22	-3.366	0.002**
	DJ, (m/s) (Left - side)	0.71 ± 0.18	0.79 ± 0.15	-5.473	0.000**
	DJ, (m/s) (Right - side)	0.70 ± 0.18	0.78 ± 0.15	-4.929	0.000**
	DJ, (m/s) (Bilateral)	1.69 ± 0.37	1.75 ± 0.36	-3.133	0.004**
	5-meter sprint, (s)	0.99 ± 0.06	0.95 ± 0.09	3.625	0.001**
	10-meter sprint, (s)	1.72 ± 0.07	1.62 ± 0.10	8.324	0.000**
	Jump-spiked ball speed, (m/s)	18.20 ± 2.54	18.76 ± 2.57	-3.733	0.001**
	Jump-served ball speed, (m/s)	18.76 ± 2.93	19.34 ± 2.79	-3.201	0.003**
Changing direction ability	180° Change of Direction Speed(s)	1.13 ± 0.12	1.10 ± 0.14	3.755	0.001**

Note: EG: Experimental group (Unilateral Complex Training Group); * p<0.05 ** p<0.01

Table 4. Comparison of the differences in pre and post-test Variable between groups (n = 34)

	Variable	EG	CG	t	p - value
		Mean (SD)	Mean (SD)		
Maximum strength	1RM Squat	17.97 ± 25.04	23.12 ± 25.87	-1.049	0.294
	Isometric Mid-Thigh Pull (Bilateral)	277.15 ± 414.48	323.61 ± 389.56	-1.595	0.111
	Isometric Mid-Thigh Pull (Left - side)	266.98 ± 305.07	156.29 ± 267.66	-2.245	0.025*
	Isometric Mid-Thigh Pull (Right - side)	284.37 ± 249.07	165.78 ± 253.58	-2.257	0.024*
Explosive power	CMJ, (cm) (Left - side)	2.72 ± 2.40	1.21 ± 2.02	-2.097	0.036*
	CMJ, (cm) (Right - side)	3.01 ± 2.39	1.08 ± 1.56	-4.232	0.000**
	CMJ, (cm) (Bilateral)	1.73 ± 3.00	4.62 ± 4.31	-3.802	0.000**
	DJ, (m/s) (Left - side)	0.08 ± 0.08	0.03 ± 0.08	-3.011	0.003**
	DJ, (m/s) (Right - side)	0.07 ± 0.07	0.04 ± 0.08	-2.490	0.013*
	DJ, (m/s) (Bilateral)	0.06 ± 0.11	0.10 ± 0.18	-0.613	0.540
	5-meter sprint, (s)	0.04 ± 0.07	0.02 ± 0.04	-2.087	0.037*
	10-meter sprint, (s)	0.09 ± 0.10	0.05 ± 0.06	-2.622	0.009**
	Jump-spiked ball speed, (m/s)	0.56 ± 0.87	0.86 ± 1.05	-1.897	0.058
	Jump-served ball speed, (m/s)	0.59 ± 1.07	0.92 ± 1.08	-1.050	0.294
Changing direction ability	180° Change of Direction Speed, (s)	0.08 ± 0.13	0.04 ± 0.06	-0.908	0.364

Note: CG: Control group (Bilateral Complex Training Group); EG: Experimental group (Unilateral Complex Training Group)* p<0.05 ** p<0.01

improvements in all 15 variables of maximum strength, explosive power, and changing direction ability, with all P-values less than 0.05 (see Tables 2 and 3).

Comparison of differences in changes between the experimental group and the control group before and after the experiment. Results show that in terms of maximum strength, there are significant differences in Isometric Mid-Thigh Pull (Left) and Isometric Mid-Thigh Pull (Right) (p <0.05). In terms of explosive power, there are significant differences in the indicators CMJ (Left), CMJ (Right), CMJ (Bilateral), DJ (Left), DJ (Right), 5m sprint, and 10m sprint

(p < 0.05). The p - values of other indicators are all greater than 0.05, indicating no significant differences. (see Table 4).

Discussion

Based on the T-test results in Table 2 and Table 3, After 8 weeks of intervention training, both unilateral and bilateral complex training significantly improved the maximum strength, explosive power, and change-of-direction ability of male university volleyball players. In terms of maximum strength, both groups showed very significant gains in 1RM

Squat and Isometric Mid-Thigh Pull, with slightly higher bilateral improvements in overall strength and slightly higher unilateral gains in single-leg force. In terms of explosive power, the unilateral group exhibited greater percentage improvements in single-leg vertical jumps (CMJ and DJ) and short sprints (5m and 10m), while the bilateral group achieved better gains in bilateral CMJ and ball speed performance. Both groups also showed very significant improvements in all explosive power indicators ($p < 0.01$). Regarding change-of-direction ability, both groups improved significantly ($p < 0.05$), with the unilateral group showing slightly greater progress. These findings align with previous research by Appleby et al. (2019), Häkkinen et al. (1996), and Cormier et al., (2020), supporting that both training modes are effective, though unilateral complex training may provide greater benefits for unilateral strength, speed, and agility-related tasks.

Based on the T-test results in Table 4, both unilateral and bilateral complex training significantly improved performance indicators, but with different strengths. In terms of maximum strength, there was no significant difference between the groups in 1RM Squat and Bilateral Isometric Mid-Thigh Pull, indicating similar effectiveness. However, the unilateral group showed significantly greater improvements in unilateral Isometric Mid-Thigh Pull (Left and Right), suggesting superior effectiveness in enhancing single-leg strength. This supports findings from Yang Jiaqun (2016), Appleby et al. (2019), and Zhang et al. (2023), who emphasized the distinct advantages of unilateral and bilateral training. In terms of explosive power, the unilateral group showed significantly greater improvements in unilateral CMJ and DJ, as well as in 5- and 10-meter sprints, while the bilateral group showed better performance gains in bilateral CMJ and volleyball-specific skills like jump-spiked and jump-served ball speed though the latter showed no statistically significant difference. These results align with studies by Drouzas et al. (2020), and Zhang et al. (2025), who demonstrated that unilateral training is more effective for improving single-leg power and short-distance sprinting, while bilateral training better supports tasks involving two-foot takeoffs. Regarding change-of-direction ability, no significant difference was found between groups, though the unilateral group showed a slightly greater improvement. This supports the idea that while both training types are effective, unilateral training may be more beneficial for movements requiring single-leg force production. Overall, each method has unique advantages unilateral training excels in enhancing unilateral power and speed, whereas bilateral training is more effective for bilateral explosive tasks and volleyball-specific performance.

Conclusions

In summary, the findings of this study indicate that both unilateral and bilateral complex training significantly enhance maximum strength, explosive power, and change of direction ability in male university volleyball players over an 8-week period. While both groups showed significant within-group improvements, the unilateral complex training group demonstrated greater performance gains across eight key indicators, particularly in unilateral strength and speed-related measures such as isometric mid-thigh pull, countermovement jump (CMJ), drop jump (DJ), and short-distance sprints. Conversely, the bilateral training group showed superior outcomes in bilateral CMJ and demonstrated slight advantages in bilateral

force output and ball velocity during spike and serve actions. These results suggest that unilateral complex training is more effective for improving lower-limb functional performance related to unilateral power and sprinting, whereas bilateral training is more beneficial for enhancing bilateral explosive movements. Overall, unilateral complex training appears to offer broader performance benefits for volleyball athletes.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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Визначення впливу унілатерального та білатерального комплексного тренування на максимальну силу, вибухову потужність та здатність до зміни напрямку руху волейболістів

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

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Історія питання. Унілатеральні та білатеральні комплексні тренування — це методики, які поєднують в собі виконання різних вправ, спрямованих на розвиток різних груп м'язів та фізичних якостей, як-от сила, потужність, швидкість та рівновага. Розуміння найефективнішої стратегії тренувань є надзвичайно важливим для оптимізації фізичної результативності, специфічної для волейболу.

Мета дослідження. Це дослідження мало на меті порівняти вплив унілатерального та білатерального комплексного тренування на працездатність нижніх кінцівок, зокрема максимальну силу, вибухову потужність та здатність до зміни напрямку руху, в університетських волейболістів чоловічої статі, а також оцінити цей вплив у межах цієї конкретної групи.

Матеріали та методи. Загалом 68 чоловіків-волейболістів віком 18-26 років з чотирьох університетів Шанхаю було розподілено за методом рандомізації на групи унілатерального ($n = 34$) та білатерального ($n = 34$) тренування. Обидві групи провели восьмитижневі програми з комплексного тренування, розроблені на основі рекомендацій експертів. До показників результативності належали: присідання з одним повторенням максимальної ваги (1ПМ), ізометричне підтягування середини стегна (ПСС), стрибок із контррухом (СКР), стрибок у глибину (СГ), спринти на 5 і 10 метрів та тести на спритність. Дані було проаналізовано за допомогою t-критеріїв для парних і незалежних вибірок та коефіцієнта d Коена з метою оцінки розмірів ефектів.

Результати. Обидва протоколи тренувань значно поліпшили усі показники результативності ($p < 0.05$ або $p < 0.01$). Група, яка займалася унілатеральним тренуванням, продемонструвала істотно вищі показники у виконанні одностороннього ПСС, СКР і СГ на одній нозі, а також у спринті на короткі дистанції. Група, в якій застосовувалася методика білатерального тренування, мала кращі результати у двосторонньому СКР і дещо вищу швидкість польоту м'яча, однак виконання лише білатерального СКР досягло статистичної значущості. Істотної різниці в здатності змінювати напрямок руху встановлено не було, проте використання методики унілатерального тренування забезпечило дещо більший прогрес.

Висновки. Результати дослідження показують, що як унілатеральне, так і білатеральне комплексне тренування є ефективними для підвищення працездатності нижніх кінцівок. Однак унілатеральне тренування може бути кориснішим щодо поліпшення показників потужності однієї ноги та спринту, тоді як білатеральне тренування сприяє кращому розвитку білатеральної вибухової сили та навичок, специфічних для волейболу.

Ключові слова: унілатеральне тренування, білатеральне тренування, працездатність нижніх кінцівок, вибухова потужність, швидкість спринту, університетські волейболісти.

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