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Section: Original Investigation

Article Title: Single-Leg Power Output and Between-Limb Imbalances in Team-Sports Players: Unilateral vs. Bilateral Combined Resistance Training

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Single-leg power output and between-limb imbalances in team-sports players: unilateral vs. bilateral combined resistance training

Submission Type: Original Investigation

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Abstract

**Purpose:** The aim of the present study was to compare the effects of unilateral and bilateral resistance training on single-leg power output, between-limb imbalance (BLI), bilateral deficit (BLD), change of direction (COD), linear sprinting and jumping performance in young elite basketball players. **Methods:** Twenty-two young (U-16 to U-19) male basketball players were randomly assigned either to exclusive unilateral (UNI) (n=11) or bilateral (BIL) (n=11) resistance training group during a 6-week period. Both groups training consisted of 3 unilateral or bilateral 90º-back squat sets. A post-determined number of repetitions was set until power output dropped to <10% of maximum power (MP) output. Additionally, both groups performed 2 sets of 5 unilateral or bilateral drop jumps and 2 sets of 5 unilateral or bilateral countermovement jumps (CMJ). Pre- and post-training, performance was assessed by an incremental bilateral and unilateral squat load test, a multiple COD test (V-cut test), a 15 m sprint (7.5+7.5 m) with one 180º-COD performed both right (180º-RCOD) and left (180º-LCOD) leg test, a 25-m sprint test (5 and 15-m split time) and a CMJ test. **Results:** Within-group analyses showed substantial improvements in 180º-RCOD, bilateral and unilateral MP, 25-m sprint test and CMJ in both groups. Between-group analyses showed substantial better results in 180º-LCOD, MP with right and left leg, BLI and BLD in UNI compared to BIL. **Conclusions:** Both combined training programs substantially improved most of the physical fitness tests, though only UNI reduced between-limbs asymmetry and achieved greater enhancements in those actions that mostly required applying force unilaterally in basketball players.

**Keywords:** asymmetry, change of direction ability, instantaneous feedback, plyometrics, resistance training
Introduction

The ability to perform high-intensity actions (HIA) is an important prerequisite for successful participation in most team-sports.\textsuperscript{1,2} Several studies have reported that HIA such as acceleration,\textsuperscript{3} maximum running speed,\textsuperscript{4} change of direction (COD) ability\textsuperscript{5} and explosive power\textsuperscript{6} can facilitate on-field competitive performance. For example, 83\% of goals in soccer are preceded by at least one powerful action (e.g., linear sprint) of the scoring or the assisting player.\textsuperscript{7} Given the importance of HIA for team-sports performance, training strategies that ensure their optimal development are continuously being investigated.

Specificity is important for training-induced adaptations.\textsuperscript{8} Most HIA in team-sports require players to produce force off a single leg when running, bounding, landing, changing direction or jumping. Moreover, some of the most career threatening injuries (e.g., anterior cruciate ligament [ACL]) typically occur to a one-legged loaded leg and when both limbs are loaded the main load is typically on one leg (i.e., the injured leg).\textsuperscript{9,10} In this regard, between-limb imbalance in strength and power, assessed as the between-limb imbalance (BLI) or limb symmetry index, has been considered as a valid and useful tool to detect players at high injury risk (i.e., 4-fold in players with >10\% asymmetry) of lower extremity injury\textsuperscript{11} as well as to a successful return to sport after an ACL injury.\textsuperscript{12} Additionally, functional asymmetries might also play a role in performance. For example, greater symmetrical team-sports players (assessed via unilateral vertical jump or distance reached during a dynamic balance test) seem to be faster than their asymmetrical counterparts during linear and COD sprint tests.\textsuperscript{13} Therefore, team-sports players might benefit from strength training interventions aiming to enhance physical performance and/or reduce injury risk that incorporate unilateral strength exercises.
Despite the potential benefits that unilateral strength training might offer to team-sports athletes, very little information is currently available on the topic. For example, it has been shown that the inclusion of unilateral plyometric exercises (i.e., combined with bilateral exercises or isolated) was more effective to improve functional performance (i.e., jumping, sprinting, COD ability) in young “recreational” soccer players than bilateral plyometric training alone.\textsuperscript{14} However, this study employed only plyometric exercises and single leg performance (e.g., power output and strength) measurements were not conducted. Moreover, to the best of our knowledge, only one study has to date investigated the effect of bilateral and unilateral strength training showing similar improvements on physical performance (i.e., linear sprint, maximal strength and COD) in highly trained team-sports players.\textsuperscript{15} As such, this scarce information makes quite difficult to give solid, evidence-based recommendations. Therefore, the aim of the present study was to compare the effects of unilateral and bilateral training on single leg power output, BLI, bilateral deficit (BLD), COD, linear sprinting and jumping performance in young elite basketball players.

**Methods**

**Subjects**

Twenty-two young (U-16 to U-19) highly trained male basketball players (age: 16.9 ± 2.1 years, body mass: 77.6 ± 9.3 kg, height: 189.7 ± 6.9 cm) belonging to an elite basketball club voluntary took part in the present study. Data collection took place in the fourth month of the competitive season after 2 months of preseason period and 1 month of competition. All players participated on average in ~ 11 hours of combined basketball (6 sessions) and strength/power (2 sessions) trainings plus two competitive matches per week. At the time of the study, all players were competing at national level (i.e., Spanish Basketball National League). Furthermore, some players (n=5) were also competing at international level (i.e.,
European and World Basketball Championship). Every player had a minimum experience of 2 years (range: 2 to 5 years) in strength training. Written informed consent was obtained from both the players and their parents before beginning the investigation. The present study was approved by the institutional research ethics committee, and conformed to the recommendations of the Declaration of Helsinki.

Study Design

Using a controlled and randomized study design (ABBA distribution), players were divided into 2 training groups who performed either exclusive unilateral (UNI) (n=11; age: 16.8 ± 1.7 years, body mass: 76.9 ± 8.6 kg, height: 190.4 ± 6.9 cm) or bilateral (BIL) (n=11; age: 16.7 ± 1.7 years, body mass: 74.9 ± 9.6 kg, height: 188.9 ± 7.5 cm) strength training based on their ranked physical performance. Tests were performed on an indoor basketball court 1 week before training and 1 week following the training period. Tests included a 25-m running sprint test (with a 5 and 15 m split time), a countermovement jump (CMJ) test, a multiple COD test (V-cut test), a 15 m sprint time (7.5 m + 7.5 m) with one 180º-COD performed both right (180º-CODR) and left (180º-CODL) leg test, and an incremental bilateral and unilateral squat load test. Players were familiarized with the exercise procedures prior to the commencement of each test. They were asked not to perform intense exercise on the day prior to a test and not to consume their last meal at least 3 hours before the scheduled test time.

Procedures

Training intervention

Participants performed two resistance training sessions per week, in addition to their normal strength training for 6 consecutive weeks. The strength training sessions, performed for both groups, typically included injury prevention exercises (i.e., eccentric strength,
balance and coordination exercises). UNI training consisted of 3 unilateral 90º-squat sets (i.e., until thighs were parallel to the floor) of a post-determined number of repetitions. This number was determined by stopping the set when power output (measured via a linear encoder) dropped to <10% of a target power output (MP<10%) established at the start of the first set in each session. A computer was placed in front of the participants so that they could see the power output in each repetition. Following this, players performed 2 sets of 5 unilateral drop jumps (DJ) from a height of 0.25 m, and 2 sets of 5 unilateral CMJ, while the only difference in BIL was the jump height in DJ (0.5 m). Vertical DJs were performed during session 1 whereas horizontal DJs were executed in session 2. Between-set recovery was 3 min in both groups. During unilateral squats, the supporting leg (foot) was placed on an adjustable bench located behind the player. Furthermore, the starting leg in each exercise (i.e., squats, DJ and CMJ) throughout the UNI training was always the less powerful leg as assessed at the unilateral squat pre-test. The concentric phase was performed as fast as possible (with the feet not leaving the floor) and the eccentric phase was slower (i.e., self-selected and never exceeding 3 s) in both training groups. The load was progressively increased in the 90º-squat exercise in both groups: 80% of maximum power (MP) load (week 1), 90% of MP load (week 2), 100% of MP load (week 3, 4, and 5) and 80% of MP load (week 6). Squat exercise was monitored in each training session through a linear encoder (SmartCoach Power Encoder SPE-35, SmartCoach Europe AB, Stockholm, Sweden).

V-cut test

Players performed a 25 m sprint with 4 COD of 45º each 5 m and is described elsewhere. The V-cut test was repeated twice and 3 min of passive recovery was provided between repetitions. Time was recorded by timing gates (Microgate, Bolzano, Italy) and the best (fastest) trial was retained. Reliability scores were 0.92 (90% confidence interval [CI]:
0.87; 0.95) for intraclass correlation coefficient (ICC), and 1.4% (90%CI: 1.2; 1.7%) for coefficient of variation (CV).

180° change of direction test (180°-COD)

Players performed a 15 m sprint test with a 180°-COD. Players started from a line, sprinted for 7.5 m, crossed a line with either right or left foot and came back to the starting line as fast as possible. Both right (180°-RCOD) and left COD (180°-LCOD) was repeated twice. The front foot was placed 0.5 m before the first timing gate. At least, 2 min of between-repetitions recovery was allowed. Time was recorded by timing gates (Microgate, Bolzano, Italy) and the best time with each 180°-COD was retained. Reliability scores were 0.85 (90%CI: 0.75; 0.92) and 0.78 (0.62; 0.87) for ICC, and 1.7% (1.4; 2.1%) and 2.1% (1.8; 2.7%) for CV at 180°-RCOD and 180°-LCOD, respectively.

Incremental bilateral squat test

All squat testing was done in the Smith machine (Salter, Barcelona, Spain) starting with a 20 kg load. Data was registered by a linear encoder (SmartCoach Power Encoder SPE-35, SmartCoach Europe AB, Stockholm, Sweden). Players performed a 90°-squat descending slowly, stopped during approximately 1 s and ascending at maximal velocity to the initial upright position. The features of the test are described elsewhere. The test ended when the MP with both legs was lower than the previous load.

Incremental unilateral squat test

The procedures were similar to the incremental bilateral test. This test was also performed in a Smith Machine (Salter, Barcelona, Spain). The initial leg to be assessed was randomly selected at each load. While performing the unilateral squat in both testing and training, players placed the top of their foot of the non-executing leg on a support bar behind them (at 0.8 m height and 1 m of distance from the executing leg) to ensure the executing leg
was the only leg used to perform the squat. If these considerations during the execution were not respected, this repetition was not considered as valid. There was a pause between the eccentric and concentric phase. One repetition was performed when velocity in the concentric phase was lower than 1 m.s\(^{-1}\), whereas 2 repetitions were performed when velocity in the concentric phase was greater than 1 m.s\(^{-1}\) with both the right and left leg with each load. Between-leg recovery was 30 s within each load, and 3 min between loads. The variables retained for analysis were: MP with right leg, MP with left leg and BLI. BLI was based on limb symmetry index:\(^{11}\) BLI = MP with worse leg/MP with better leg x 100. Furthermore, BLD was also analyzed. BLD was calculated as follows: \((1 - (\text{MP with both limbs} / (\text{MP right leg} + \text{MP left leg}))) \times 100.\)\(^{18}\) ICC was between 0.88 and 0.92 and CV was between 3.4\% and 5.2\% in both unilateral and bilateral MP.

**Speed tests**

Running speed was evaluated by a 25 m sprint time (standing start) with 5 m and 15 m split times. The front foot was placed 0.5 m before the first timing gate. Time was recorded with photoelectric cells (Microgate, Bolzano, Italy). The 25 m sprint was performed two times, separated by at least 3 min of passive recovery. The best time was considered for subsequent analysis. ICC was between 0.73 to 0.88, while CV was between 1.6\% and 2.8\%.

**Countermovement jump**

Jump height was assessed using vertical CMJ (cm) with flight time measured by an Optojump (Microgate, Bolzano, Italy). Each trial was validated by a visual inspection to ensure that each landing was without any leg flexion, and players were instructed to maintain their hands on their hips during CMJ. The depth of the CMJ was self-selected. Each test was performed three times, separated by 45 s of passive recovery, and the best jump was
recorded. Reliability scores were 0.94 (90%CI: 0.80; 0.99) for ICC, and 3.3% (2.7; 3.9%) for CV.

**Statistical analyses**

Data is presented as mean ± SD. All data were first log-transformed to reduce bias arising from non-uniformity error. The standardized difference or effect size (ES, 90% confidence limit [90%CL]) in the selected variables was calculated using the pooled pre-training SD. Threshold values for Cohen ES statistics were >0.2 (small), >0.6 (moderate), and >1.2 (large). For within/between-group comparisons, the chances that the differences in performance were better/greater (i.e., greater than the smallest worthwhile change, SWC [0.2 multiplied by the between-subject standard deviation, based on Cohen’s d principle]), similar or worse/smaller were calculated. Quantitative chances (QC) of beneficial/better or detrimental/poorer effect were assessed qualitatively as follows: <1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; and >99%, almost certain. If the chance of having beneficial/better or detrimental/poorer performances was both >5%, the true difference was assessed as unclear. The Pearson product moment correlation coefficient was used to determine the relationship between different variables. The following criteria were adopted for interpreting the magnitude of correlation (r) between tests measures: ≤0.1, trivial; >0.1–0.3, small; >0.3–0.5, moderate; >0.5–0.7, large; >0.7–0.9, very large; and >0.9–1.0, almost perfect. If the 90%CL overlapped small positive and negative values, the magnitude of the correlation was deemed unclear; otherwise the magnitude was deemed to be the observed magnitude.
Results

Participants

Only players who participated in >85% of all training sessions were included in the final analyses. Consequently, 4 of the 22 players were excluded for various reasons. None of the players got injured during the strength training sessions. As a result, 18 players (age: 16.8 ± 1.9 years, body mass: 77.4 ± 9.2 kg, height: 189.7 ± 7 cm) were included in the final analyses. The final sample size for each training group was n=9 for UNI and n=9 for BIL. In spite of dropouts, no significant differences were found between-groups at baseline.

Mean number of repetitions and power output in the 90°-squat exercise

Overall, BIL performed 7.8 ± 0.5 repetitions and 362.8 ± 75.0 W in each set, while UNI executed 8.1 ± 1.3 repetitions and 305.3 ± 35.9 W with right leg and 8.3 ± 1.1 repetitions and 303.7 ± 39.0 W with left leg. The 10% power output decrement corresponded to a 12.7 ± 0.8% decrement in the mean velocity during all trainings in both groups. The progression throughout relative maximum power intensity (80%, 90% and 100%) is illustrated in Figure 1. No substantial differences were found between the mean number of repetitions of any group or leg. Conversely, BIL showed substantial greater mean power output than both UNI with right (17.3% [CL90%: 0.5; 36.9]; ES= 0.86 [0.03; 1.69]; QC= 91/7/2%) and UNI with left (15.3% [CL90%: 0.9; 27.6]; ES= 0.87 [0.05; 1.69]; QC= 91/7/2%), while no substantial differences were reported between right and left legs.

Incremental load test

MP with both legs was achieved with 47.8 ± 6.8 kg in the BIL group and 48.3 ± 7.9 kg in the UNI group. MP with the right leg was achieved with 34.6 ± 8.0 kg in the BIL group and 36.9 ± 6.6 kg in the UNI group. MP with the left leg was achieved with 34.3 ± 6.1 kg in the BIL group and 37.5 ± 5.6 kg were established in the UNI group.
Within group changes

Results of within group changes are presented in Table 1. Substantial performance improvements were found in 180º-RCOD, MP with both legs, left and right leg, all sprint times and CMJ after both trainings interventions (UNI and BIL). Furthermore, UNI group also substantially improved 180º-LCOD and BLI, while substantially increased its BLD.

Between-group changes

Results from between-group analysis are illustrated in Figure 1. The improvements in 180º-LCOD (2.6% [CL90%: -0.6; 5.8]; QC = 81/15/3%), MP with right leg (12.3% [CL90%: -0.7; 26.9]; QC = 88/9/3%), MP with left leg (12.8% [CL90%: -1.9; 29.8]; QC = 84/12/3%) and BLI (53.1% [CL90%: 48.0; 350.7]; QC = 85/10/5%) were substantially greater in UNI than in BIL. Furthermore, a substantial greater BLD (29.2% [-5.2; 76.0]; QC = 83/13/4%) was found in UNI compared to BIL. A possibly performance improvement in CMJ was also found in UNI compared to BIL.

Discussion

The aim of the present study was to compare the effects of UNI and BIL combined resistance training on squat power output, sprinting, COD and jumping performance in highly-trained young basketball players. The main findings of the study were: 1) post-intervention single-leg squat maximum power output (i.e., MP with left and right leg) improvements were substantially greater after unilateral than bilateral training; 2) between-limb imbalances and bilateral deficit in back squat maximum power output were substantially reduced or increased, respectively, only after unilateral training; and 3) small to large post-training improvements in power output, sprinting and jumping performance were found in both groups.
Most of the game-related HIA in team-sports such as accelerating, braking, changing direction, jumping, landing or kicking typically occur with both legs loaded asymmetrically. These mainly unilateral actions can also be linked to some of the most common (e.g., ankle and knee sprains) and serious (e.g., ACL) injuries suffered by team-sports players. Therefore, within this cohort, the improvement of single-leg function (e.g., unilateral power or strength) may be important from both on-field physical performance and protection against injury. In the present study, post-training improvements in single-leg power output (i.e., MP with left and right leg) were substantially greater in UNI compared to BIL (Table 1 and Figure 1). While to the authors’ knowledge this is the first time that power output has been assessed after UNI training with a linear encoder (previously a Margaria-Kalamen stair-climb test or unilateral vertical jumping power have been used), present results are somehow at odds to what was reported in a recent study with rugby players. Similar absolute strength unilateral and bilateral improvements (i.e., 1RM) were shown after both bilateral (i.e., back squat) (ES=1.36) and unilateral (i.e., elevated split squat) (ES=1.25) resistance training. In addition to the different metrics used (maximal power output vs. 1RM), between-studies differences in the training load prescription (instantaneous feedback with individualized number of reps vs. pre-defined number of reps), training orientation (power vs. maximal loads) or exercise selection (strength training and plyometrics vs. strength training) might be behind the somehow contrasting findings. To the authors’ knowledge, there are no other published studies examining the effect of unilateral or bilateral strength training on single-leg strength and/or power in team-sports players.

Another interesting finding of the present study was the substantial reduction in BLI observed after UNI training, which was likely greater than the BIL group. Despite the apparent critical relevance of between-limb imbalance for both protection against injury and performance, to the best of our knowledge, this is the first study to assess the impact of a
training intervention on BLI in team-sports players. Therefore, comparisons are not possible. A previous study evaluated the effect of unilateral balance/strength exercises in comparison to a control group in young tennis players.\textsuperscript{21} Interestingly, a substantial decrease in BLI in a single-leg horizontal (ES=2.07) and lateral hop (ES=2.08) was found in the experimental group while the control group maintained their BLI values (ES=-0.06 to -0.02). Therefore, despite that more research is needed, it seems that training interventions involving unilateral strength and balance/motor control actions might prove effective in reducing BLI.

In a similar way, bilateral deficit was largely increased only after UNI training with \textit{likely} greater changes than the BIL group. Considering the observed larger improvements in single leg power output in comparison with two-legged squat in the UNI group, these findings were expected.\textsuperscript{22,23} In this regard, changes in unilateral squat power output were strongly correlated with changes in BLD (0.85 [CL90\%: 0.64; 0.94]). On the contrary, the large effect of BIL training on unilateral power and its negative effect on BLD was somewhat unexpected. It is uncertain whether the habitual strength training sessions or the addition of the unique combined training program originated these adaptations but the latter is an intriguing possibility that clearly deserves further research.

COD ability is believed to depend on a myriad of factors such as technique, linear sprinting speed, leg-muscle qualities and anthropometry.\textsuperscript{24} As such, the improvement of leg-muscle qualities (e.g., reactive strength, concentric strength and power, BLI) might aid in enhancing COD ability. Our results showed that UNI training induced some small improvements in COD ability in the 3 tests conducted while only 1 test was improved after the BIL training (Table 1). The observed magnitude of the substantial changes (i.e., improvements) in COD ability was lower (ES=0.28 to 0.48) than what has been previously reported in late adolescents team-sports players after either bilateral or unilateral strength training (ES=0.48 to 1.86).\textsuperscript{15,25} Others, have reported no substantial changes (ES=-2.0 to 0.3)
in COD ability after a complex-contrast training or a combined conditioning training (strength + aerobic high intensity + specific rugby skills) in highly trained team-sports players.\textsuperscript{26-28} Between-studies outcome differences might be due to different training approaches employed such as training volume (7 sets in the present study vs. 14-18 sets\textsuperscript{25} or 44 vs. 82-100 repetitions per training session), players’ RT experience (2 years vs. 1 year\textsuperscript{15}), training intensity (near or equal to maximum power loads and plyometrics vs. 75-92\% 1RM\textsuperscript{15}) or the moment of the competitive season (pre-season vs. in-season). BIL training was never more effective than UNI at improving COD performance (Figure 1). Somehow similar, previous studies comparing UNI vs. BIL training have shown substantially greater improvements after UNI in comparison to BIL,\textsuperscript{15,25} supporting the idea of the principle of specificity.\textsuperscript{8} In the present study, UNI training was more effective than BIL at enhancing left-side single COD performance (180°-LCOD), whereas an unclear outcome was provided in 180°-RCOD (Figure 1). The fact that UNI training was superior to BIL in improving only the ability to turn to the left side might be related to the specific overload of that (weak) side imposed only during UNI training. It has been reported that during bilateral back squat training, vertical ground reaction force asymmetry is significantly different between-limbs (4.3\%) at the beginning of a set.\textsuperscript{29} Furthermore, this magnitude given by percentage difference between left and right legs in vertical ground reaction force favoring the preferred leg is maintained at the end of a set in asymmetric subjects.\textsuperscript{29} In this regard, our basketball players were all right leg-dominance (determined from the self-reported preferred leg via a questionnaire) and were considered as asymmetric participants. Hence, these differences could be due to players whom only train bilaterally might exert much effort with right leg during the whole set while players training unilaterally were systematically exposed to left leg efforts.
The strength training approach employed in the present study (i.e., combined training compounded by resistance training + plyometrics), rather than isolated traditional strength training methods, is considered as an optimal training strategy to enhance sprint performance. As such, substantially better linear sprinting performance was found after the training period in both groups (i.e., UNI and BIL). These results (ES=0.55 to 0.92) are within the range or even greater (ES=-0.1 to 0.87) of previously training studies after unilateral or bilateral RT studies in male team-sports players. In the present study, no substantial differences in sprinting performance between UNI and BIL training interventions were found. Previous studies on the impact of UNI and BIL strength training on sprinting performance reported contrasting findings. One of those studies reported substantial better sprinting performance after UNI training in comparison to BIL (ES=0.24 vs. 0.58), whereas a greater BIL training effect (ES=-0.10 vs. 0.70) was found in the other study. Differences in the team-sports players investigated (college rugby vs. academy rugby vs. basketball), sprinting distance assessment (10 vs. 25 vs. 40 m) and the training performed (RT + plyometrics with individualized reps number vs. RT with pre-defined reps vs. combined training) might explain these between-studies differences. Further research is warranted to better understand the effect of unilateral or bilateral RT on linear sprinting performance.

The present results indicated that 6 weeks of combined strength training had a substantial beneficial impact on jumping performance (ES-UNI=0.47; ES-BIL=0.27). Despite jumping performance is considered an important physical fitness component in most team-sports, this is the first study that has investigated the effect of unilateral RT on CMJ performance in highly-trained team-sports players. Therefore, direct comparisons are not possible. The CMJ changes found in the present study after UNI training (ES=0.47) are within the range (ES=0.19 to 0.79) of previously published reports after different bilateral training strategies in young male team-sports players. In this regard, interventions
including bilateral RT, complex training and explosive strength training have typically reported greater training effects (ES=0.53, 0.62, 0.78)\textsuperscript{23,27-29} than plyometric training (ES=0.33)\textsuperscript{22} and complex-contrast strength training (ES=0.19).\textsuperscript{27} It should be noted that all studies that have found greater training-induced changes in CMJ than in the present study were performed with younger (14 vs. 17 years) or more inexperienced in strength training (novices vs. 2 year-experienced) team-sports players. In this regard, it is well known that age and training background can influence the magnitude in the training adaptation.\textsuperscript{6} Moreover, basketball players are typically required to perform much more jumps during matches and practices than soccer players. As such, it might be possible that this population (basketball players) would have more difficulties in improving vertical jumping performance.

A unique feature of the present study was that both training groups performed a post-determined number of repetitions on the 90º-squat exercise based on a minimum accepted target power output. While this could be seen as a potential limitation for non-equivalent training volumes, the overall number of repetitions in each condition throughout the training program was similar. However, we are unable to know whether the target power output challenge and/or the provision of instantaneous feedback may have affected the positive results since the conditions were the same for both training groups. It is expected that an unknown training duration (reps/set) may have implications on anticipatory/feedforward components (pacing strategies) by means of adjustments in power output.\textsuperscript{34} About feedback provision, even though the literature concerning its long-term effectiveness is scarce, it is believed to be a useful tool to individualize and optimize training interventions by providing a more consistent performance while avoiding those repetitions that might produce a negative effect in neuromuscular performance.\textsuperscript{35}

There are some limitations in this study. It is uncertain whether performance was enhanced through the effect of individualized maximal power training, the combination of
strength and plyometrics or both training strategies. As such, further studies are warranted to analyze the influence of performing a pre- vs. post-determined number of repetitions based on a minimum target power and different combinations of resistance training methods. In addition, more functional tests such as unilateral jumps in different axes or the Star Excursion Balance Test to assess dynamic stability should be included.

**Conclusions**

Combined unilateral training reduced between-limbs differences (i.e., asymmetry) and achieved greater enhancements in those actions that require applying force unilaterally when compared with bilateral training. Additionally, unilateral training also induced substantial adaptations in jumping, linear sprinting and COD ability.

**Practical applications**

Strength training is typically prescribed bilaterally although the most important actions in team-sports (i.e. jumps, sprints, COD) are performed mainly unilaterally. As such, based on the present results, the inclusion of unilateral strength training exercises can be of interest for players with between-leg strength and power asymmetries as well for players who want to enhance their ability to produce force unilaterally. Finally, the use of a target power output challenge by providing instantaneous feedback might be seemed as an effective tool not only to optimize strength training but also to motivate athletes.
References


Figure 1. Mean repetitions (number) and mean power (watts) for each training. Blue lines represent mean repetitions and red lines represent mean power throughout different relative maximum power intensities (80%: week 1; 90%: week 2; 100%: week 3-5; 80%: week 6).
Figure 2. Efficiency of the unilateral (UNI) compared to bilateral (BIL) strength training program to improve multiple change of direction (V-cut test), change of direction of 180° with left (180°-LCOD) and right (180°-RCOD) leg, maximum power bilaterally (MPB), maximum power with right leg (MPR), maximum power with left leg (MPL), between-limb imbalance (BLI), bilateral deficit (BLD), 5, 15 and 25 m sprint time and countermovement jump performance (CMJ) (bars indicate uncertainty in the true mean changes with 90% confidence limits). Trivial areas were the smallest worthwhile change (SWC) (see methods).
Table 1. Changes in athletic performance following unilateral strength training (UNI, \(n=9\)) or bilateral strength training (BIL, \(n=9\)). Data are mean ± SD.

<table>
<thead>
<tr>
<th>Variables</th>
<th>UNI ((n=9))</th>
<th>BIL ((n=9))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
</tr>
<tr>
<td>V-cut test (s)</td>
<td>6.57 ± 0.23</td>
<td>6.50 ± 0.18</td>
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<tr>
<td>180°-RCOD (s)</td>
<td>3.54 ± 0.15</td>
<td>3.47 ± 0.10</td>
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<tr>
<td>180°-LCOD (s)</td>
<td>3.55 ± 0.17</td>
<td>3.46 ± 0.15</td>
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<tr>
<td>MPR (W)</td>
<td>406.9 ± 48.5</td>
<td>466.3 ± 72.8</td>
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<tr>
<td>MPL (W)</td>
<td>271.2 ± 36.8</td>
<td>370.4 ± 50.4</td>
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<tr>
<td>BLI (%)</td>
<td>9.6 ± 3.8</td>
<td>4.8 ± 1.3</td>
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<tr>
<td>BLD (%)</td>
<td>24.8 ± 8.9</td>
<td>36.8 ± 7.7</td>
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<tr>
<td>5-m (s)</td>
<td>1.13 ± 0.05</td>
<td>1.07 ± 0.06</td>
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<tr>
<td>15-m (s)</td>
<td>2.54 ± 0.08</td>
<td>2.48 ± 0.1</td>
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<tr>
<td>25-m (s)</td>
<td>3.84 ± 0.12</td>
<td>3.75 ± 0.15</td>
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<tr>
<td>CMJ (cm)</td>
<td>37.4 ± 4.2</td>
<td>39.8 ± 5.1</td>
</tr>
</tbody>
</table>

Note. V-cut test: 25 meters sprint with 4 changes of direction; 180°-RCOD: 15 meters (7.5 + 7.5) sprint with one change of direction of 180° performed with right leg; 180°-LCOD: 15 meters (7.5 + 7.5) sprint with one change of direction of 180° performed with left leg; MPB: maximum power exerted during bilateral squat; MPR: maximum power with right leg exerted during unilateral squat; MPL: maximum power with left leg exerted during unilateral squat; BLI: between-limb imbalance; BLD: bilateral deficit; 5-m: 5 meters sprint; 15-m: 15 meters sprint; 25-m: 25 meters sprint; CMJ: countermovement jump; Standardized differences: Effect size; CL: Confidence limits.