Unilateral and Bilateral Lower-Body Resistance Training Does not Transfer Equally to Sprint and Change of Direction Performance

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Abstract

Appleby, BB, Cormack, SJ, and Newton, RU. Unilateral and bilateral lower-body resistance training does not transfer equally to sprint and change of direction performance. *J Strength Cond Res* 34(1): 54–64, 2020—Given maximal strength can be developed using bilateral or unilateral resistance training, the purpose of this study was to determine the magnitude of transfer of unilateral or bilateral resistance training to sprint and change of direction (COD) performance. Thirty-three trained participants (average training age = 5.4 ± 2.9 years and 1 repetition maximum [1RM] 90° squat = 177.6 ± 26.7 kg) completed either a bilateral group (BIL, $n = 13$), unilateral (UNI, $n = 10$), or comparison (COM, $n = 10$) 18-week randomized controlled training design. Training involved 2 lower-body, volume-load–matched resistance sessions per week (6–8 sets × 4–8 reps at 45–88% 1RM), differing only in the prescription of a bilateral (squat) or unilateral (step-up) resistance exercise. Strength was assessed through 1RM squat and step-up, in addition to 20-m sprint and a customized 50° COD test. The effect size statistic ± 90% confidence limit (ES ± CL) was calculated to examine the magnitude of difference within and between groups at each time point. BIL and UNI groups improved their trained and nontrained strength exercise with an unclear difference in adaptation of squat strength (ES = −0.34 + 0.55). Both groups improved 20-m sprint (ES: BIL = −0.38 ± 0.49 and UNI = −0.31 ± 0.31); however, the difference between the groups was unclear (ES = 0.07 ± 0.58). Although both groups had meaningful improvements in COD performance, bilateral resistance training had a greater transfer to COD performance than unilateral resistance training (between-groups ES = 0.59 ± 0.64). Both bilateral and unilateral training improved maximal lower-body strength and sprint acceleration. However, the BIL group demonstrated superior improvements in COD performance. This finding potentially highlights the importance of targeting the underlying physiological stimulus that drives adaptation and not exercise selection based on movement specificity of the target performance.

Key Words specificity, squat, step-up

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Introduction

Resistance training is a common place for team sport athletes with the ultimate aim being the transfer of heightened physical capacity to superior sporting performance (33). Bilateral resistance exercises such as squats, deadlifts, and weightlifting derivatives have been demonstrated to improve strength and 5–40-meter speed performance and thus incorporated in resistance training programs for elite athletes (7,19,37). However, given that key phases of athletic performance such as sprinting and change of direction (COD) occur in 1 leg, unilateral resistance training is perceived to offer greater movement specificity than bilateral exercises (32,40).

Owing to a single base of support, unilateral resistance exercises are considered sport specific (22,31). The unstable nature has demonstrated altered neuromuscular activation levels in gluteal, hamstring, and quadricep muscle groups compared with bilateral movements (11,30). Several lower-limb musculotendinous injuries are attributed to neuromuscular deficits, which may be rectified by targeted unilateral training (43). Coupled with the resemblance of sporting movements, unilateral exercises are recommended for rehabilitation requiring enhanced neuromuscular coordination (4). However, the unstable base may also reduce the magnitude of external load required for strength development and subsequent improvement in sports performance in trained individuals (3).

Studies investigating the effect of unilateral vs. bilateral resistance training have reported similar strength outcomes,

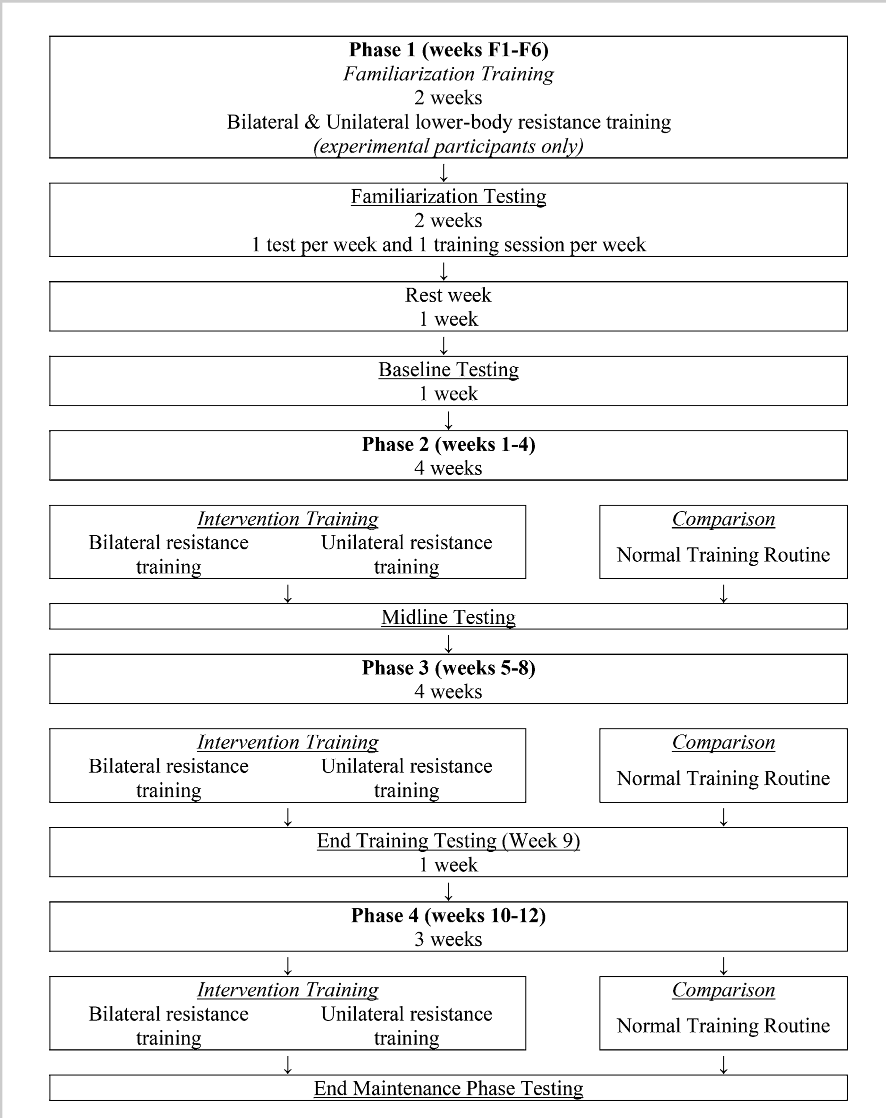

Figure 1. Schematic representation of study design.

inferring equal benefit using either of the two (32,40). Investigating bilateral and unilateral resistance training involves several practical limitations making sound methodological designs challenging and findings difficult to apply. These include the training age of subjects, inadequate familiarization and training period duration, unadjusted differences in pretraining performance, insufficient resistance training stimulus, and supplemental exercise prescription (such as plyometrics) (13,15,40). For example, although improvements in unilateral basketball performance have reported the adolescent age of subjects (average age 17 years), this may have little application to mature athletes (15). Furthermore, isolating the transfer of unilateral or bilateral resistance training is problematic where studies have incorporated additional generic lower-body resistance training or unilateral and bilateral plyometrics (13,15). Sufficient overload may also have been compromised by short periods of intervention (40) or magnitude of resistance training intensity by external loading (13,15). Therefore, such constraints make it difficult to isolate effective resistance training strategies for athlete training programs.

Although inherently unstable on 1 foot, the barbell step-up (step-up) is a unilateral exercise that uses considerable external loading capable of driving strength adaptation. Despite the initial bilateral base of support, the majority of the movement is entirely unilateral, unlike other "unilateral" exercises such as lunges, or rear foot elevated split squats, that are asymmetrical rather than purely unilateral. Although the step-up seems to exhibit sport specificity as an unstable strength development exercise, little research has examined its application to improvements in sprint acceleration and COD performance.

Therefore, the aim of this study was to examine the changes in sprint acceleration and COD ability as a result of resistance training using either bilateral (squat) only or unilateral (step-up) only. Our hypothesis is that unilateral training would be advantageous to COD performance. The outcomes of this investigation may provide insight regarding the role of movement-specific, lower-body resistance training for enhancing athletic performance.

Methods

Experimental Approach to the Problem

This investigation involved a 3-phase, 3-arm, randomized controlled design training intervention incorporating a 6-week familiarization phase, an 8-week training intervention, and a 3-week maintenance phase (Figure 1). Although training was provided, an extended familiarization phase was deemed necessary to eradicate potential learning effects from

Table 1. Participant characteristics at the commencement of the training intervention and testing.*†

Group	Age (y)	Height (cm)	Body mass (kg)	Squat (1RM:BM)
Bilateral (n = 13)	21.8 (3.3)	184.3 (5.9)	101.3 (12.8)	1.74 (0.24)
Unilateral (n = 10)	23.1 (4.1)	186.3 (5.1)	104.6 (11.5)	1.80 (0.15)
Comparison (n = 10)	24.6 (5.3)	183.2 (7.4)	93.1 (10.4)	1.71 (0.09)

*RM = repetition maximum; BM = body mass.
†Data are presented as mean ± *SD* for all variables. Age = chronological age; squat 1RM:BM = 1 repetition maximum 90° back squat divided by participant body mass.

the unfamiliar unilateral strength exercise (5). This period also enabled all subjects to regularly practice the COD test. Baseline testing occurred at the conclusion of this familiarization period before the training intervention. The purpose of the maintenance phase was to observe changes as per an in-season phase common in competitive sporting environments. In addition to lower-body maximal strength testing (evaluated by 1 repetition maximum [1RM] squat and step-up), subjects were assessed for 20-m sprint acceleration and COD. Training was equated between experimental groups, with the only distinction being the volume-load prescription of squats (bilateral resistance training group [BIL]) or step-ups (unilateral resistance training group [UNI]) during 2 lower-body resistance training sessions per week. Training was conducted during a development academy rugby preseason phase.

Subjects

A total of 49 male subjects were recruited from a state rugby union academy program and grade club competition for the 3 groups, of which 33 (mean ± *SD*: age = 22.4 ± 4.1 years, height = 185.3 ± 5.5 cm, and body mass = 102.9 ± 12.0 kg) completed all required aspects of the testing and training for inclusion in the final analysis (1 rugby player got injured and 15 failed to complete sufficient training or testing sessions) (Table 1). After baseline testing, balanced randomization procedures were used to stratify the subjects into the experimental arms at a ratio of 1:1, by resistance training experience (≤4 vs. >4 years) and relative maximal strength (≤1.5 vs. >1.5 squat 1RM to body mass ratio). Another group was allocated as a comparison group and was permitted to maintain normal activity and to be present only for testing. Resistance training compliance was set at 80% completion for the intervention phase (weeks 1–8 of training) and 66% for the maintenance phase (being 2 of the 3 sessions). All subjects were over the age of 18, notified of the potential risks involved and gave their written informed consent. This study was approved by Edith Cowan University's Human Research Ethics Committee. All subjects commenced free of injury or previous injury history, which may have inhibited performance.

Procedures

Training Programs. Training was performed during a typical subelite rugby preseason phase (Table 2) (39). Skill sessions generally involved rugby-specific training including physical contact. Upper-body resistance training was individually prescribed for strength or hypertrophy, whereas all lower-body resistance training sessions were volume load matched for squats (BIL group) or step-ups (UNI group), following the format presented in Table 3. Because the investigation was embedded in a preparation phase, speed and agility sessions were incorporated as part of a standard rugby preparation phase and were common to all subjects. The only training aspect to differ between the 2 groups was the allocation of lower-body bilateral or unilateral resistance training, at individually prescribed loads as a percentage of 1RM obtained at baseline, mid-testing, and post-testing (Table 4). The training stimulus was matched according to the following volume-load equation: volume load = number of sets × total number of repetitions × %1RM (16) (Figure 2). All

Table 2. Weekly training schedule.*

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday and Sunday
Strength (upper)	Skills	Rest day	Strength (lower)	Conditioning strength (upper)	Rest day
Speed Skills	Strength (lower)		Speed Skills		

*Strength = gym-based resistance training session; speed = acceleration and change of direction; skills = team rugby training, technical and tactical skill development; rest day = no structured training; conditioning = bike fitness sessions.

Table 3. Example of lower-body training program for each four-week mesocycle.

Exercise		Phase 2, sets and reps range	Phase 3, sets and reps range
Warm-up exercises	Split squat/lunge type movement (body mass)	3 × 5	3 × 5
	Landing (hops, jumps, in multiple directions, etc.).	3 × 3	3 × 3
Intervention exercise	Squat or step-up	As per Table 5	
Specific injury prevention exercises	Hamstring	Day 1: 3 × 6–10	Day 1: 4 × 4–10
	Nordics (day 1)	Day 2: 2 × 6–10	Day 2: 3 × 4–8
	Glute-ham raises and Romanian deadlift (day 2)		
	Calf raises	Double leg: 3 × 10–25	Single leg: 3 × 10–25

lower-body sets were performed under the guidance of at least one coach to assist with load prescription, performance monitoring, and technical execution. A linear position transducer (GymAware PowerTool Version 5; Kinetic, Canberra, Australia) was used to record barbell velocity and provide feedback for every repetition during training alone.

Testing Protocol. Subjects had a minimum of 3-day recovery between their last lower-body strength session and physical assessment. Testing occurred at the same time of the day on each occasion. Subjects commenced with a standardized 20-minute warm-up procedure that consisted of stationary bike riding (7 minutes of steady-state intensity plus 3 minutes of short interval efforts of increasing intensity), followed by lower-body mobility exercises and concluded with prescribed countermovement jumps. At the conclusion of the warm-up, all subjects completed field tests of 20-m speed and COD capability followed by a 30-minute rest period before maximal dynamic strength testing (1RM squat and 1RM step-up tests) with a 20-minute rest in between. To minimize the effects of fatigue and potentiation, subjects were randomly assigned to a speed first or COD first group of even numbers. Similarly, squat and step-up groups were randomly assigned to 2 even groups. Where a test could be performed on the left or right leg, the order was randomized. The testing order remained consistent for each subject at all test sessions. Verbal encouragement was provided by testers and subjects.

Table 4. The reps, sets, and percentage 1RM loading for squats and step-ups for each session.*†

				% 1RM							
Phase	Week	Session	Reps per set	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8
Phase 2	1	1	8	45	55	64	64	64	64	64	64
		2	8	45	55	64	64	68	68	55	55
	2	3	6	45	55	64	68	72	72	72	72
		4	6	45	55	64	68	72	72	60	60
	3	5	6	45	55	64	64	68	68	72	76
		6	6	45	55	64	67	70	70	60	60
	4	7	6	45	55	64	68	68	72	76	80
		8	6	45	55	68	72	62	62	–	–
Phase 3	5	9	4	45	55	65	72	76	76	Rest sets	
		10	4	45	55	65	72	76	81	72	72
	6	11	4	45	55	65	76	81	81	85	85
		12	4	45	55	65	72	72	72	67	67
	7	13	4	45	55	65	76	81	83	85	85
		14	4	45	55	65	76	81	85	67	67
	8	15	4	45	55	65	76	81	83	85	88
		16	No training–recovery for final testing session								
Phase 4	10	17	4	45	55	65	76	83	88	67	67
	11	18	4	45	55	65	76	83	88	67	67
	12	19	4	45	55	65	76	83	88	67	67

*RM = repetition maximum.
†For the step-up, the reps are the total for the set, (i.e., 4 reps indicate 2 on each leg for a total of 4). Sessions 8 and 9 had 2 less sets, either side of the mid-test session.

Data Acquisition and Analysis Procedures: Box Height Allocation. During the familiarization

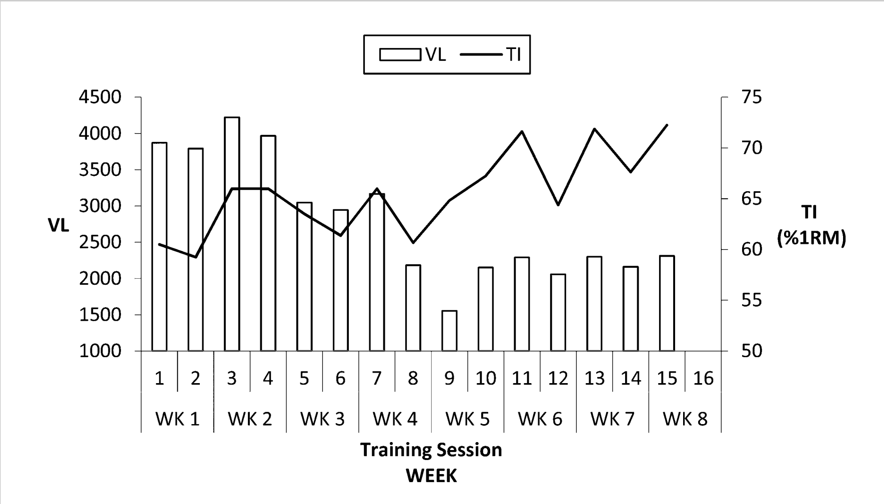

Figure 2. Prescribed volume load (VL) and training intensity (TI) as a percentage of 1RM of the training intervention (phases 2 and 3) based on repetitions × sets × %1RM (12). 1RM = 1 repetition maximum.

period, all subjects were assigned a box step-up height and barbell back squat depth. On each subject, a permanent marker was used to draw lines joining the greater trochanter to lateral tibial condyle, and the lateral tibial condyle to the lateral malleolus of the right leg. Subjects were videoed from a lateral perspective performing barbell step-ups on a series of 7 wooden boxes from 300 to 420 mm and analyzed using computer software (Kinovea, version 0.8.15). The subject was allocated the box height that resulted in a 90° knee angle at foot contact. Subjects were also filmed from a lateral perspective performing light barbell back squats in a power cage (York Fitness, Rocklea, Australia) where a light elastic band was looped around the right-hand side of the frame, marked with centimeter graduations. Subjects performed a series of squats to the band, where their knee angle was measured with a goniometer and confirmed by video analysis. Subjects were allocated a squat depth using the rack centimeter markings that represented a knee angle flexion depth of 90°.

One Repetition Maximum Testing. Subjects performed a series of warm-up sets, 4 repetitions at 50% of 1RM, 3 repetitions at 70%, 2 repetitions at 80%, and 1 repetition at 90%, each separated by 3-minute rest (28). After the warm-up, a series of maximal attempts were performed until a 1RM was obtained. All testing occurred inside a power rack with the safety bars raised to chest height for step-up testing. The step-up was deemed a fail if the subject could not extend the leg fully on the box without assistance from the uninvolved limb. A squat would be deemed a fail if the subject did not descend to their target depth or achieve full extension without assistance. All repetitions were observed by an accredited strength coach (Australian Strength and Conditioning Association, Level 3) and at least one other coach for spotting and encouragement. The order of squat or step-up was randomized.

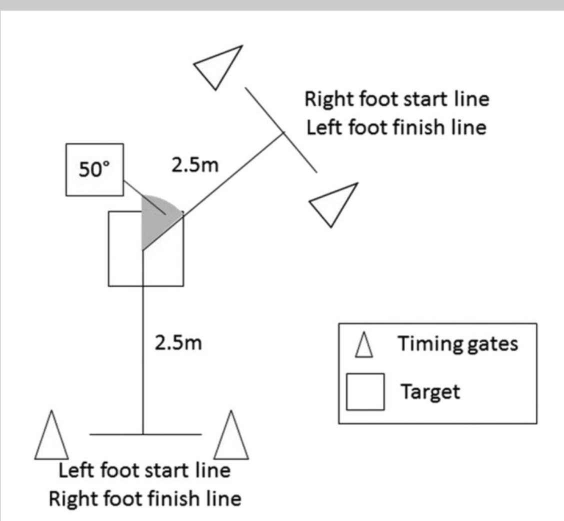

Figure 3. Figure of change of direction course.

Change of Direction Testing. A customized single 50° COD test (48) was used, which involved a 2.5-m approach, a 50° COD, and a 2.5-m exit sprint, for a total distance of 5 m (Figure 3). This test was designed to limit total sprint distance, which can influence COD assessment, isolate performance of a single-leg COD, limit tests involving multiple changes of direction (e.g. Illinois and 1 more) (38), and replicate rugby movement patterns for implementation with the current cohort, as opposed to an out and back test (eg., 505, T-test). The 50° angle was selected based on previous research demonstrating reductions in sprint speed with a direction change of 40° or greater (48). Test-retest reliability was established during familiarization testing ($n = 10$, pooled left and right coefficient of variation [CV] = 3.6%, and intraclass correlation coefficient [ICC] = 0.78). On an indoor surface, electronic timing gates formed a channel approximately 1.4 m wide placed at the 0- and 5-m marks with dual-beam photo cells (Speedlight; Swift Performance Equipment, Wacol, Australia) and an accuracy of 0.01 s (the

Table 5. One repetition maximum (1RM) strength of the bilateral, unilateral, and comparison groups for squat and step-up strength at baseline, week 9, and 12 for bilateral, unilateral, and comparison groups.*

	Bilateral (squat treatment)		Unilateral (step-up treatment)		Comparison	
	Squat (kg)	Step-up (kg)	Squat (kg)	Step-up (kg)	Squat (kg)	Step-up (kg)
Baseline	181 ± 26	122 ± 18	193 ± 28	135 ± 20	158 ± 14	104 ± 16
End training (week 9)	205 ± 30	132 ± 15	203 ± 28	148 ± 17	170 ± 22	105 ± 20
End maintenance (week 12)	198 ± 25	132 ± 14	205 ± 34	150 ± 22	171 ± 21	106 ± 17

*Step-up = average of right- and left-leg 1RM strength.

middle of the dual-beam gate approximately 83 cm from the ground). A minimum of 3 trials of each condition–a left foot COD and a right foot COD–with a 2-minute rest were allowed. The choice of the lead foot in the starting posture was self-selected by the subject to maximize their performance. Subjects self-initiated the run and were required to change direction by placing the correct pivot foot within a 50 × 50-cm target square, which was marked on the floor, the center of the box being 2.5 m from each gate. A trial would be invalid if the subject touched the perimeter of the taped box. A maximum of 5 trials were permitted in each direction with the fastest time used in the analysis. The use of the fastest trial for analysis is a process that has been previously used extensively (8,25,39).

Twenty-Meter Sprint Acceleration Testing. The 20-m test has been used extensively as a field- and laboratory-based assessment to measure sprint acceleration in a variety of team sports (27,44). Sprint acceleration (20 m) was assessed using dual-beam electronic timing gates (Speedlight; Swift Performance Equipment) on the same indoor surface as the COD testing. Gates were positioned at 0, 5, 10, and 20 m with the splits from the fastest 20 m used in the analysis. Subjects used a 2-point staggered start with the front foot placed at the zero line and started the sprint at their volition. Flying 15-m time was calculated as the time to sprint from the 5-m gate to the 20-m gate (9). The 5-, 10-, 20-m, and Flying 15-m sprint reliability has been previously established in our laboratory (CV%, ICC: 5 m = 6.3%, 0.90;

Table 6. Magnitude of within-group changes in speed and change of direction at weeks 9 and 12 compared with baseline for bilateral, unilateral, and comparison groups.*†

	Bilateral (squat treatment) [ES + 90% CI]	Unilateral (step-up treatment) [ES + 90% CI]	Comparison [ES + 90% CI]
5-m sprint			
Weeks 1–8 (training)	−0.60 ± 0.78‡ (moderate)	−0.37 ± 0.41‡ (small)	0.49 ± 0.53‡ (small)
Weeks 10–12 (maintenance)	0.57 ± 0.68‡ (small)	−0.12 ± 0.63 (unclear)	−0.62 ± 0.67‡ (moderate)
Weeks 1–12	−0.13 ± 0.65 (trivial)	−0.47 ± 0.51‡ (small)	−0.13 ± 0.51 (unclear)
20-m sprint			
Weeks 1–8 (training)	−0.38 ± 0.49 (small)	−0.31 ± 0.31 (small)	0.54 ± 0.30§ (small)
Weeks 10–12 (maintenance)	0.04 ± 0.48 (unclear)	0.11 ± 0.48 (unclear)	−0.06 ± 0.39 (unclear)
Weeks 1–12	−0.19 ± 0.34 (trivial)	−0.23 ± 0.51 (unclear)	0.48 ± 0.28‡ (small)
COD (average of left and right legs)			
Weeks 1–8 (training)	−0.97 ± 0.32‖ (moderate)	−0.50 ± 0.54‡ (small)	−0.22 ± 0.38 (small)
Weeks 10–12 (maintenance)	0.30 ± 0.40 (small)	−0.14 ± 0.68 (unclear)	0.04 ± 0.30 (unclear)
Weeks 1–12	−0.90 ± 0.40§ (moderate)	−0.54 ± 0.61‡ (small)	−0.18 ± 0.19 (trivial)

*ES ± 90% CI = effect size ± 90% confidence interval; COD = change of direction.
†Effect size classified according to: <0.2 as trivial; 0.2–0.59 as small; 0.6–1.19 as moderate; and 1.2–2.0 as large. Results were classified as "unclear" when the 90% CI crossed substantially positive and negative values (0.20 and −0.20). Baseline adjustments: comparisons were adjusted due to the step-up being the stronger or faster group at baseline.
‡Percent likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: >75% as "likely."
§Percent likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: >95% as "very likely."
‖Percent likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: >99.5% as "almost certainly."

Table 7. Magnitude of change in speed and change of direction between the bilateral and unilateral groups for each training cycle.*†

	5-m sprint	20-m sprint	COD (average of left and right)
Weeks 1–8 (training)	0.11 ± 0.88 (unclear)	0.07 ± 0.58 (unclear)	0.72 ± 0.55‡ (moderate§)
Weeks 10–12 (maintenance)	−0.67 ± 0.94‡ (moderate‖)	0.07 ± 0.65 (unclear)	−0.46 ± 0.67 (unclear)
Weeks 1–12	−0.45 ± 0.83 (unclear)	−0.04 ± 0.59 (unclear)	0.59 ± 0.64‡ (small§)

*COD = change of direction; ES = effect size.
†Effect size classified according to: <0.2 as trivial; 0.2–0.59 as small; 0.6–1.19 as moderate; and 1.2–2.0 as large. Results were classified as "unclear" when the 90% CI crossed substantially positive and negative values (0.20 and −0.20). Baseline adjustments: comparisons were adjusted due to the step-up being the stronger or faster group at baseline.
‡Percent likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: >75% as "likely."
§Performance adaptation benefits the bilateral group.
‖Performance adaptation benefits the unilateral group.

10 m = 5.2%, 0.98; 20 m = 5.4%, 0.99; and Flying 15 m = 4.7%, 0.99) (10). As per COD testing, the fastest trial was used for the analysis (8,25).

Statistical Analyses

Descriptive statistics (mean ± *SD*) for strength, speed, and COD were calculated for each testing occasion. The difference within the bilateral, unilateral, and comparison groups compared with baseline at end-training and end-maintenance phases was calculated using a customized Excel spreadsheet (20). Data were log transformed to reduce bias due to nonuniformity of errors and analyzed using the effect size statistic (ES) ± 90% confidence limits (CLs) (20). In addition, the difference in the change from baseline to week 9 and 12 between the treatment groups was also calculated. In all analyses, the outcome was adjusted to the mean of the stronger or faster group in each performance task (20). The magnitude of the effect in both analyses was classified according to the following scale: 0.2–0.6 as small, 0.6–1.2 as moderate, and 1.2–2.0 as large (38). In addition, the likelihood of the effect exceeding the smallest practically important difference (0.2) was represented using the following scale: >75% as "likely," >95% as "very likely," and >99.5% as "almost certainly" (2). Effects less than 75% likely to exceed an ES of 0.2 were considered "trivial" and where there was a >5% chance of the effect being simultaneously positive and negative, the effect was considered "unclear."

Results

Descriptive strength information is presented in Table 5. The BIL and UNI groups exhibited meaningful improvements in

Table 8. Magnitude of change in speed and change of direction between the bilateral and comparison groups for each training cycle.*†

	5-m sprint	20-m sprint	COD (average of left and right)
Weeks 1–8 (training)	0.91 ± 1.22‡ (moderate‖)	1.04 ± 0.62§ (moderate‖)	−0.92 ± 0.99 ‡ (moderate‖)
Weeks 10–12 (maintenance)	−0.91 ± 1.14‡ (moderate‖)	−0.06 ± 0.66 (unclear)	0.81 ± 0.93‡ (moderate‖)
Weeks 1–12	−0.05 ± 1.04 (unclear)	0.78 ± 0.47§ (moderate‖)	−1.14 ± 0.80§ (moderate‖)

*COD = change of direction; ES = effect size.
†Effect size classified according to: <0.2 as trivial; 0.2–0.59 as small; 0.6–1.19 as moderate; and 1.2–2.0 as large. Results were classified as "unclear" when the 90% CI crossed substantially positive and negative values (0.20 and −0.20). Baseline adjustments: comparisons were adjusted due to the step-up being the stronger or faster group at baseline.
‡Percent likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: >75% as "likely."
§Percent likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: >95% as "very likely."
‖Performance adaptation benefits the bilateral group.

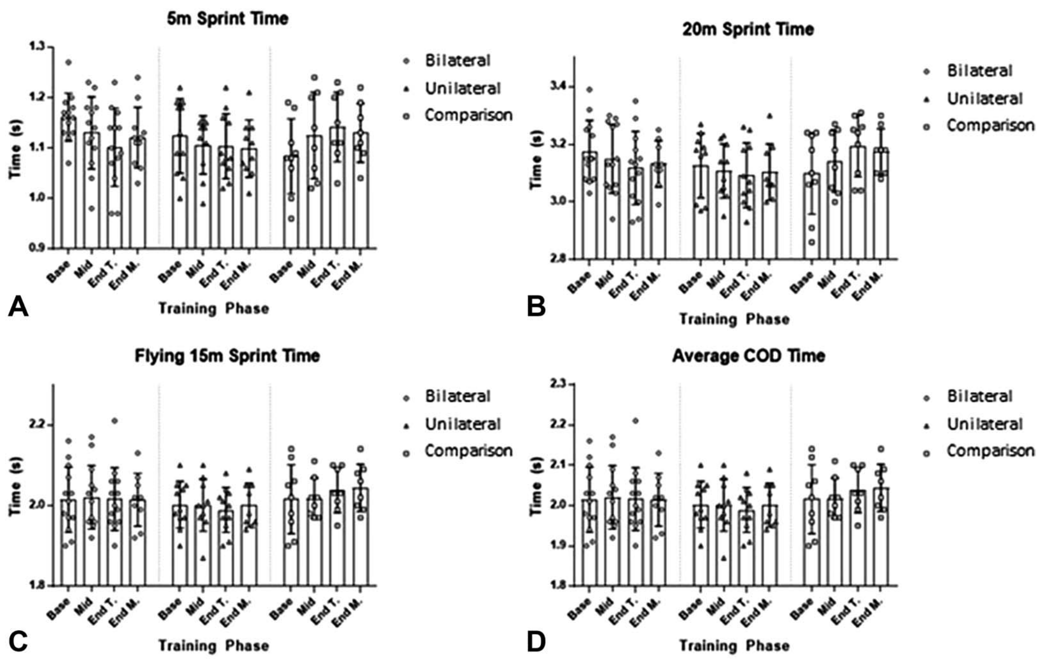

Figure 4. Mean (±*SD*) and individual responses in the bilateral group (BIL), unilateral group (UNI), and comparison group (COM) for average left and right change of direction (COD) time. Training phase: Base = baseline testing; Mid = mid-testing; End T = end training; End M = end maintenance.

1RM strength (BIL 1RM squat ES = 0.79 ± 0.40, 99% very likely; and UNI 1RM average step-up ES = 0.63 ± 0.17, 99.9% almost certainly). The difference in squat strength between the groups after the 8-week training intervention was unclear (−0.34 ± 0.55), with a small difference in 1RM step-up strength favoring the UNI group (ES = 0.41 ± 0.36, 84% likely). The changes in speed and COD within each group at weeks 9 and 12 compared with baseline are presented in Table 6. Both the BIL and UNI groups showed meaningful improvements in speed (BIL 5-m ES = −0.60 ± 0.78; UNI 5-m ES = −0.37 ± 0.41; BIL 20 m = −0.38 ± 0.49; and UNI 20 m = −0.31 ± 0.31) and average COD (BIL ES = −0.97 ± 0.32; and UNI ES = −0.50 ± 0.54) during the training period. The difference in the change from baseline to weeks 9 and 12 between the BIL, UNI, and COM groups is displayed in Tables 6–9. Although both the BIL and UNI

Table 9. Magnitude of change in speed and change of direction between the unilateral and comparison groups for each training cycle.*†

	5-m sprint	20-m sprint	COD (average of left and right)
Weeks 1–8 (training)	0.95 ± 0.63§ (moderate¶)	0.96 ± 0.43‖ (moderate¶)	0.57 ± 0.1.34 (small¶)
Weeks 10–12 (maintenance)	−0.36 ± 0.90 (unclear)	−0.17 ± 0.60 (unclear)	−0.57 ± 1.53 (small¶)
Weeks 1–12	0.54 ± 0.71‡ (small¶)	0.79 ± 0.55§ (moderate¶)	0.00 ± 1.36 (unclear)

*COD = change of direction; ES = effect size.
†Effect size classified according to: <0.2 as trivial; 0.2–0.59 as small; 0.6–1.19 as moderate; and 1.2–2.0 as large. Results were classified as "unclear" when the 90% CI crossed substantially positive and negative values (0.20 and −0.20). Baseline adjustments: comparisons were adjusted due to the step-up being the stronger or faster group at baseline.
‡Percent likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: >75% as "likely."
§Percent likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: >95% as "very likely."
‖Percent likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: >99.5% as "almost certainly."
¶Performance adaptation benefits the unilateral group.

exhibited small to moderate changes in 5 and 20 m, the difference between the BIL and UNI groups was "unclear" (5 m = 0.11 ± 0.88 and 20 m = 0.07 ± 0.58) (Table 6). When comparing the adaptation between the BIL and UNI groups, the BIL showed moderate improvement in COD capacity (ES = 0.72 ± 0.55, 94% likely) (Table 6). The changes in speed and COD are presented in Figure 4 and Table 9.

Discussion

This investigation revealed that although lower-body strength can be developed using unilateral or bilateral resistance exercise, a similar magnitude of adaptation transfers differently to acceleration and COD performance. Both groups displayed similar magnitudes of strength improvement as a result of bilateral or unilateral training and exhibited small improvements in 20-m sprint time, indicating the influence of maximal strength development to sprint acceleration capacity. However, a different mechanistic adaptation occurred in the BIL training group with superior transfer to COD performance.

Although strongly correlated (37), gains in lower-body maximal strength do not guarantee improvements in sprint performance (12), and critical to improved performance is the transfer of newly gained strength (47). Both the BIL and UNI groups made small to moderate improvements in 5- and 20-m sprint time during the eight-week training phase, coinciding with improvements in lower-body strength. This finding is in support of previous short-term and meta-analysis studies that have demonstrated improvements in strength positively influencing short-distance sprint performance (7,37). Interestingly, the difference between the 2 training groups in 5- and 20-m speed was unclear due to the wide confidence interval that seems to be the function of varied individual adaptation. Initial sprint acceleration is greatly influenced by the production of peak ground reaction force and impulse for overcoming inertia (21,23). In the current study, it may be that the underlying physiological stimulus of the squat and the step-up–targeted adaptations are essential for improved sprint acceleration capacity. It is likely that prescribed strength stimulus and subsequent improvements in lower-body strength of each group enhanced force generation capacity required for sprint acceleration (24).

Given the large percentage of maximal speed that can be attained by team sport athletes over short distances, studies have reported "Flying" times to remove the initial acceleration phase (10,46). Although 20-m time decreased, the majority of improvement in both intervention groups was realized in the first 5 m as demonstrated by the trivial change in flying 15-m time (Figure 4C). Sprinting in team sport athletes has been characterized by 2 phases–acceleration and maximal velocity (45), and maximum strength has a greater impact on the acceleration phase (12). Although 20 m is classified as an acceleration phase, the results indicate that the current training program had a greater impact on the initial 5-m acceleration component. However, the unclear results make it difficult to determine whether bilateral training or unilateral training is a superior stimulus.

Although acceleration and COD have been demonstrated to be distinct qualities, both have also been shown to be positively related to maximal strength (6,42). It could be postulated that the transfer of newly acquired maximal lower-body strength to single-leg athletic performance would be heightened by developing that strength unilaterally (29,40). Both groups improved strength, speed, and COD ability. However, unilateral training was less effective than bilateral training for improving COD performance (COD average, weeks 1–8, between groups ES: 0.72 ± 0.55, 94% very likely). The difference in COD capacity between the 2 groups is an important finding that requires explanation. The ability to change direction first requires the athlete to arrest momentum in the original direction, before applying impulse in a new direction (17,42). Because initial steps in a sprint start are primarily concentric in nature, this may explain the similar benefit of the squat and the step-up training (34). However, the ability of an athlete to tolerate eccentric load is an essential neuromuscular capacity for COD performance (41,42).

Although speculative given the role of eccentric strength in COD performance (41,42), the presence of an eccentric phase in the squat may have provided stimulus to this group that the step-up group did not. Both the back squat and step-up were performed with rapid and forceful triple extension (concentric phase). However, the step-up is essentially performed as a concentric-dominant action onto the box, with a controlled eccentric descent and a recovery between repetitions. By contrast, the squat is performed with an eccentric action immediately before the concentric extension. Given eccentric training specifically improves eccentric strength, it may be that it is the contraction specificity, and not the unilateral or bilateral nature of the exercise (i.e. joint angle and unilateral stability), that explains the difference in enhanced COD performance (35). Previous research has demonstrated relationships between eccentric or reactive strength, to COD performance (42,48). Further biomechanical investigation comparing the squat and step-up and their relationship to COD may provide additional insight. The results of this study support training based on targeting the underlying neuromuscular demands and not the similarity in appearance to the target performance.

An important aspect of the training program design was the inclusion of a three-week maintenance phase typical of decreased training volume experienced by team sport athletes during periods of travel or frequent competition. It is known that strength and speed adaptations developed during a preseason cannot be maintained without specific in-season maintenance (1,18). A resistance training frequency of 1 session per week has been demonstrated sufficient to maintain lower-body strength and 40-m speed (14,36). Within the current training study, the 20-m speed results proved unclear for each group during this maintenance phase with both groups appearing to demonstrate individual variation in adaptation. The individual variation to 1 session per week over 3 weeks suggests that coaches should monitor meaningful sprint performance changes in their athletes to determine the necessary individual dose for speed maintenance during periods of interrupted training. An additional speed training stimulus may be warranted for identified athletes.

It is important to consider the following limitations when interpreting the results. Complexity exists in equating strength training workloads between the BIL and UNI groups, an issue recognized in previous research in bilateral and unilateral resistance training, which may result in unequal training stimulus between the groups, especially given the lack of the eccentric phase in the step-up, which may have been beneficial for squat COD improvement (26,40). A training complication may exist in the practical implications of the relative distribution of sprint training. During sprint acceleration training in a team sport setting, even a sprint focused on 20 m, which inherently contains a 0–5-m acceleration component. Therefore, the 0–5-m distance is trained with every sprint acceleration, and training for 0–5-m sprint acceleration may have been biased. Training studies with actively competitive subjects are also potentially confounded by the concurrent skill-based training. The current cohort were actively engaged in a preseason period of high training load where variations in position-specific training content may have influenced individual adaptations, particularly in rugby union with distinct position-specific skill sets that were not accounted for within the allocation or analysis of the groups. This may have affected fatigue levels for training or the application of speed and agility distribution. Finally, as this program was prescribed to a training squad, it was impractical to blind subjects and coaches from the treatment intervention.

Practical Applications

The results of this study provide further insight regarding specificity when selecting resistance exercises and the transfer of improved capacity to performance. This study demonstrates that maximal force capacity developed in resistance training–regardless of bilateral or unilateral training parameters–may be transferred to sprint acceleration where the common requirement is the ability to produce initial high levels of force with greater reliance on concentric strength. However, for COD performance, coaches should select exercises that address the underlying neuromuscular requirements of the task and not just similarity in appearance to the target performance. In this regard, increasing eccentric strength is a necessary strategy. This study has demonstrated that strength developed unilaterally (step-up) or bilaterally (squat) can transfer to sprint acceleration performance. Coaches may be confident incorporating unilateral or bilateral resistance exercises for strength development with positive implications for sprint acceleration. However, sprint acceleration and COD are distinct qualities and may require specific development and transfer strategies. Although the step-up exercise resulted in strength and speed benefits, additional eccentric stimulus may be required to enhance training for COD ability. Resistance training program design for improved athletic performance should consider the underlying neuromuscular physiology of contraction type and overload as critical elements of exercise selection.

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