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Specificity and transfer of lower-body strength: influence of bilateral or unilateral lower-body resistance training

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ABSTRACT

In order to examine the development of lower body strength using either bilateral or unilateral resistance training developmental rugby players (n = 33; mean training age = 5.4 ± 2.9 years; one repetition maximum (1RM) 90° squat = 178 ± 27 kg;) completed an 18-week randomised controlled training design (Bilateral group (BIL), n = 13; Unilateral group (UNI), n = 10; Comparison, n = 10). The 8-week training phase involved two lower body, volume-load matched resistance sessions per week (6-8 sets x 4-8 reps at 45-88% one repetition maximum [1RM]), differing only in the prescription of a bilateral (back squat) or unilateral (step-up) resistance exercise. Maximum strength was assessed by a randomised order of 1RM back squat and step-up testing and analysed for within- and between group differences using effect sizes (ES ± 90% confidence limits [CL]). Both training groups showed practically important improvements in their trained exercise (ES ± 90% CL: BIL = 0.67 ± 0.48; UNI = 0.74 ± 0.38) with transfer to their non-trained resistance exercise (BIL step-up = 0.27 ± 0.39: UNI squat = 0.42 ± 0.39). The difference between-groups in adaptation of squat strength was unclear (BIL ES = -0.34 ± 0.55), whilst the UNI group showed an advantage in step-up training (ES = 0.41 ± 0.36). The results demonstrate practically important increases in lower body strength can be achieved using bilateral or unilateral resistance training and development of that strength may be expressed in the movement not trained, supporting the transfer of strength training between exercises of similar joint movements and muscles. Coaches may choose to incorporate unilateral strength training where the prescription of bilateral training may be inhibited.

Keywords: Strength training, squat, step-up.

INTRODUCTION

Specificity and transfer are important considerations for the design of resistance training programs to improve athletic performance (528, 590). Resistance exercises differ slightly in terms of contraction type (eccentric, concentric or isometric), contraction velocity and joint angles; each driving subtly different physiological adaptations (472). Maximising adaptation from resistance training to athletic performance is paramount in resistance programming. Many training studies demonstrating the transfer of strength to improved performance have incorporated bilateral resistance exercises (e.g. squat, deadlift, power clean).(115, 258, 278) An advantage of bilateral exercise is the magnitude of external load involved and the resulting development of maximal strength (115, 490, 527). As a result, these exercises are frequently incorporated in resistance training for athletes.

However, given the unilateral nature of many sporting actions (e.g. sprinting, change of direction), unilateral exercises are deemed more sport specific (388, 480). Whilst the smaller base of support of unilateral compared to bilateral exercises requires altered neuromuscular coordination (stability and joint co-contraction) for successful performance, the cost is reduced external loading (49, 344, 386). It is important for strength and conditioning coaches to maximise the benefits of resistance training within the busy training schedule of athletes. Given the importance of sport specific resistance training in comprehensive athletic development, the comparison of the training benefit of unilateral to bilateral resistance training and performance requires further investigation.

Researchers have reported favourable transfer in relatively untrained individuals utilising the rear foot elevated split squat (RESS) as a unilateral training comparison to the bilateral back squat (511). However, the external load utilised in the RESS is comparatively low to the back squat (approximately 50% of back squat load (511)). Similar to a RESS, the barbell step-up may be a favourable alternative capable of combining instability and potentially higher external load (between 50% to 85% of 6RM squat loads (181, 570)). Therefore, the purpose of this study was to explore previously unexamined differences in lower body maximum strength as a result of training utilising the back squat (or squat (bilateral)) only, or step-up (unilateral) only.

METHODS

Experimental Approach to the Problem. This investigation involved an 18-week randomised controlled design training intervention. The design comprised of a six-week familiarisation phase (including training and testing practice and baseline testing), an eight-week training intervention (with mid and post-training testing), a recovery week and a three-week maintenance phase (concluding with final testing) (Figure 10.1). Despite the participants being well trained an extended familiarisation period was deemed necessary to eradicate the propensity for learning effects influencing results due to the unfamiliar unilateral strength exercise (67, 258). The maintenance phase was designed to replicate the minimum resistance training dose programmed during an in-season period, common in competitive sporting environments (14, 539). Lower body maximal strength testing was evaluated by a 1RM 90° squat and 90° step-up. Training was conducted during a development academy rugby pre-season phase with both intervention groups participating in all training equally, with the only distinction being the volume-load matched prescription of squats (bilateral resistance training group [BIL]) or step-ups (unilateral resistance training group [UNI]) during two lower body resistance training sessions per week.

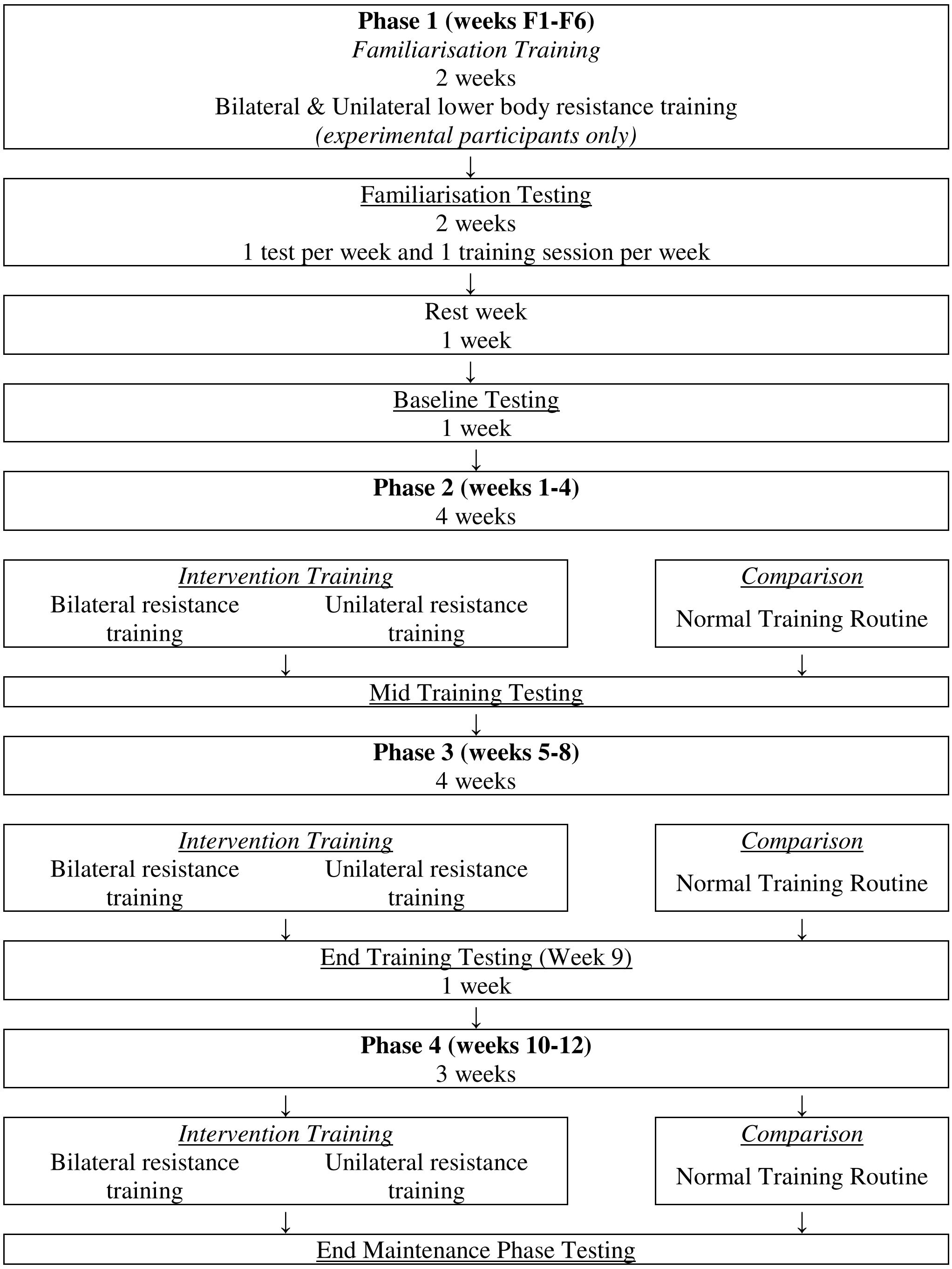

Figure 10.1 Schematic representation of study design

Subjects. Twenty-three participants recruited from a state rugby union academy program and grade club competition completed required aspects of the testing and training (age = 22.4 ± 4.1 yrs, height = 185.3 ± 5.5 cm, mass = 102.9 ± 12.0 kg). Training compliance was 96% attendance to training sessions for the intervention phase (weeks 1-8 of training), and 91% for the maintenance phase. At the completion of the baseline testing, balanced randomisation procedures were used to allocate the participants into the experimental arms at a ratio of 1:1, stratified by resistance training experience (≤4 vs. >4 years) and maximal strength (≤1.5 vs. >1.5 squat 1RM to body mass ratio). Given the training experience of the intervention cohort, accessing an appropriately matched control group (resistance training experience and relative strength), void of any training commitments was not possible. Therefore, a further cohort of 10 participants from the same rugby competition were included in a Comparison (COM) group (Table 10.1). It was not possible to isolate this group of committed recreational athletes from their training commitments, as such, they were permitted to participate in similar club rugby requirements and individual self-regulated strength and conditioning. This group was required for testing only. All participants were notified of the potential risks involved and gave their written informed consent. This study was approved by the University's Human Research Ethics Committee. All participants commenced free of injury or previous injury history which may have inhibited performance.

Table 10.1 Participant characteristics at the commencement of the training intervention and testing.

Group	Age years	Height cm	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)

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

Data Acquisition and Analysis Procedures. Squat Depth and Step-up height determination. The range of movement of an exercise has been demonstrated to produce specific adaptations (440). In order to standardise the squat and step-up, a 90° knee angle was selected as it was observed in step-up piloting to facilitate a combination of loading and technical proficiency compared to preferential greater knee angles of squatting (80). Prior to the familiarisation phase, participants attended an introductory session where individual squat depth and step-up box height were established. The 90º knee flexion squat depth was monitored by each participant squatting with a 20kg Olympic barbell (Australian Barbell Company, Victoria, Australia) and Olympic weight plates (Eleiko, Halmstad, Sweeden) to an elastic band placed on both sides of a power rack (York Fitness, Rocklea, Queensland, Australia.) at their individually determined depth. For the step-up, participants were filmed performing two repetitions of barbell step-ups on a series of boxes of incremental step height of 20mm from 300mm to 420mm. The 90° knee angle was defined as the minimum angle of the knee at contact of the lead foot on the step. All repetitions were analysed and the closest step-up box to that which resulted in a 90° knee angle was allocated to the participant.

One Repetition Maximum Testing. The 1RM protocol has been used for assessment of maximal strength (377). The protocol involved participants completing a series of warm-up sets (four repetitions at 50% of estimated 1RM, three repetitions at 70%, two repetitions at 80% and one repetition at 90%) each separated by three minutes. Following the warm-up, maximal attempts separated by a minimum of five minutes were performed until a 1RM was obtained (an average of 2.6 sets were required). Verbal encouragement was provided throughout the testing. An accredited S&C coach and at least one assistant observed each test for spotting, technique and depth monitoring. The repetition was deemed a fail if the participant could not achieve the required depth or could not return to the upright position. The coefficient of variation of 1RM squat testing has been reported as 3.5% (493). The coefficient of variation in the current cohort was 2.7% for the 1RM step-up test.

Training Programs. Training was conducted during a typical academy level rugby pre-season preparation phase (Table 10.2) (509), which involved three rugby skills sessions per week (60-90 minutes duration, including rugby specific skills, tackling, passing, etc.), two upper body resistance training sessions (individually prescribed for hypertrophy or strength; 4-7 exercises, 2-12 repetitions, 16-20 sets, 45-60 minutes duration,) two lower body resistance training sessions (the training intervention, 60 mins, [Table 10.3]), two speed and agility sessions (30-45 minutes) and an additional cardiovascular session (30-45 minutes). The training intervention involved two lower body resistance training sessions per week in which participants completed a periodised, volume-load matched (described below) program of squats (BIL group) or step-ups (UNI group). Each lower body session was separated by 48 hours recovery. The training venue, training equipment and coach supervision was consistent. The only training aspect to differ between the two groups was the individually prescribed allocation load for squats or step-ups to the lower body resistance training.

Table 10.2 Weekly training schedule.

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

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 10.3 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 weight)	3 x 5	3 x 5
	Landing (hops, jumps, in multiple directions etc.).	3 x 3	3 x 3
Intervention exercise	Squat or Step-up	(As per Table 10.4)	
Specific injury prevention exercises	Hamstring: Nordics (day 1); Glute-ham raises and Romanian Deadlift (day 2)	Day 1: 3 x 6-10; Day 2: 2 x 6-10	Day 1: 4 x 4-10; Day 2: 3 x 4-8
	Calf Raises	Double leg: 3 x 10-25	Single leg: 3 x 10-25

Participants completed their intervention exercise, under the guidance of at least one coach to assist with load prescription, technical coaching and performance monitoring. Barbell loads for the squat and step-up exercises were prescribed as a percentage of 1RM obtained at baseline, mid-testing and post-testing (prior to the maintenance phase – Table 10.4). In order to determine the influence of either exercise to performance, it was critical to match the training stimuli as closely as possible using the following volume load equation: *Volume Load = number of sets x total number of repetitions x %1RM* (241) (Figure 10.2). Additionally, a linear position transducer (LPT) (GymAware PowerTool Version 5, Kinetic, Canberra) was used to record barbell velocity and provide feedback for every repetition to each participant. The use of this device has been previously detailed (13). Performance feedback to each participant using a LPT has been demonstrated to produce superior performance during resistance training and ensured a maximal effort was achieved for all work repetitions during training (17).

Table 10.4 The reps, sets and percentage 1RM loading for squats and step-ups for each session.

Phase	Week	Session	Reps per set	% 1RM 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

Note: for the Step-up, the reps are the total for the set, (i.e. 4 reps indicates 2 on each leg for a total of 4). Session 8 and 9 had two less sets, either side of the Mid-test session.

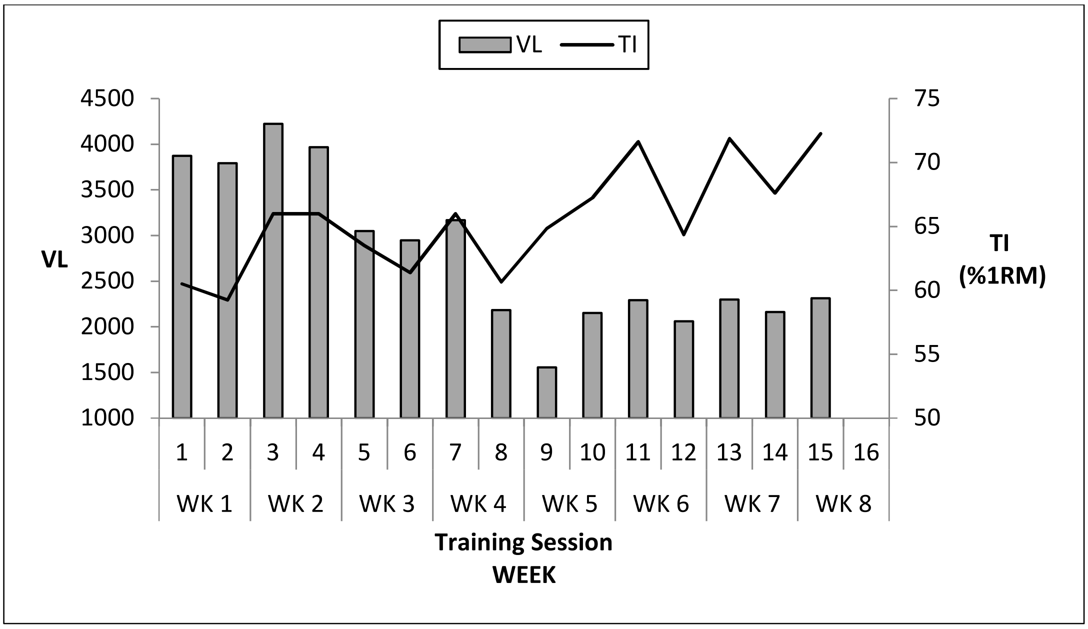

Figure 10.2 The prescribed volume load (VL) and training intensity (TI) as a percentage of 1RM of the Training Intervention (Phase 2 and 3) based on repetitions x sets x %1RM (241).

Testing Protocol. Participants had a minimum ***of*** three days recovery between their last lower body strength session and strength testing. Participants followed a standardised warm-up that included stationary bike riding and lower body mobility exercises. One repetition maximum strength testing began with a series of warm-up sets (four repetitions at 50% of 1RM, three repetitions at 70%, two repetitions at 80% and one repetition at 90%) each separated by three minutes rest, then a series of maximal attempts until a 1RM was achieved. The order of squat or step-up was randomised between all participants. Testing occurred inside a power cage, with safety bars. A squat was deemed a fail if the participant did not descend to the required depth or failed to achieve full extension without assistance. A step-up was judged as a fail if the participant could not fully extend the leg without assistance from the uninvolved limb. All repetitions were observed by an accredited strength and conditioning coach.

Statistical Analyses. Descriptive statistics (mean ± SD) for strength were calculated for each testing occasion. The difference within the Bilateral, Unilateral and Comparison groups compared to baseline at week 9 and 12 was calculated using Excel (Version 2016, Microsoft, Redmond WA)(287). Data were log transformed to reduce bias due to non-uniformity of error and analysed using the effect size statistic (ES) ± 90% confidence limits (CL) (287). In addition, the difference in the change between groups was also calculated. In all analyses, the outcome was adjusted to the mean of the stronger group in each performance task (287). 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 (19). 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" (45). Effects less than 75% likely to exceed an ES of 0.2 were considered "trivial" and where the 90%CL crossed the negative and positive 0.2 values, the ES was classified "unclear".

RESULTS

Strength performance for the BIL, UNI and COM groups and individual responses are presented in Figure 10.3. The magnitude of change within each group at the end of the 8-week training intervention and 3-week maintenance phase is presented in Table 10.5. Both the BIL and UNI groups showed meaningful improvements in 1RM strength (BIL 1RM squat ES 0.79 ± 0.40; UNI 1RM average step-up ES 0.63 ± 0.17) during the training period (Table 10.5). The between group changes at the end of the 8-week training intervention and 3-week maintenance phase are presented in Table 10.6. The results of 1RM squat strength between the BIL and UNI groups was unclear at all time points, whilst small differences in average 1RM step-up strength were observed when comparing the BIL and UNI groups during the 8-week training intervention (ES = 0.41 ± 0.36, favouring UNI group) (Table 10.6).

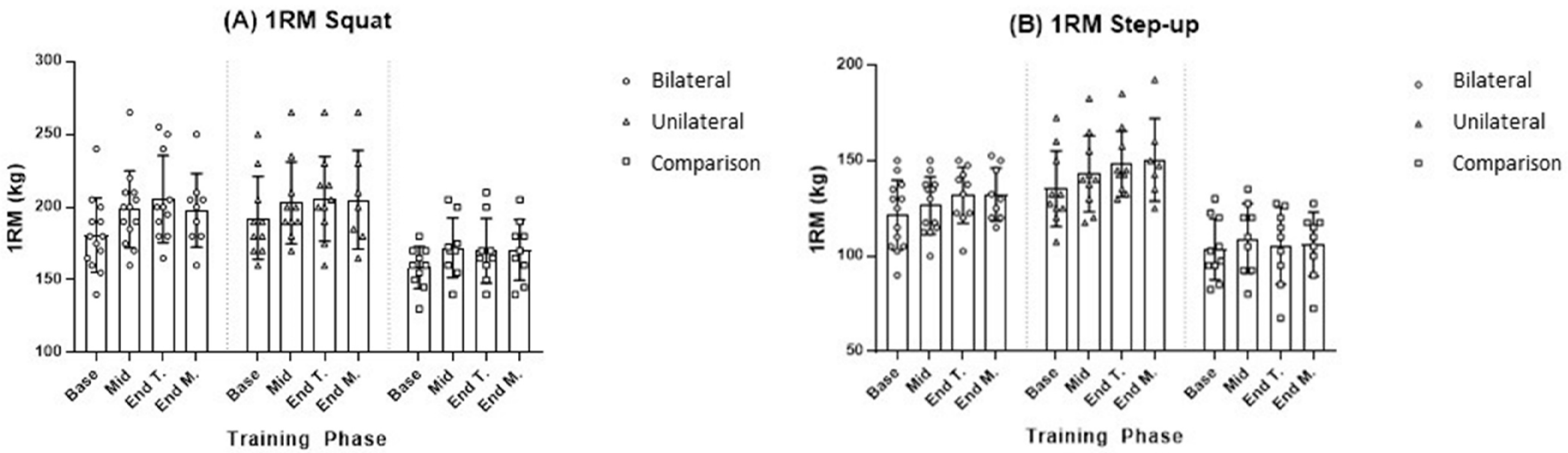

Figure 10.3 Mean (±SD) and individual responses for 1RM Squat (A) and 1RM Step-up (B) for each treatment group. Training phase: Base = Baseline testing; Mid = Mid testing; End T. = End training; End M. = End maintenance

Table 10.5 The magnitude of within group changes in strength at week 9 and week 12 compared to baseline for Bilateral, Unilateral and Comparison groups.

		Bilateral (Squat treatment) *[ES ± 90%CI]*	Unilateral (Step-up treatment) *[ES ± 90%CI]*	Comparison *[ES ± 90%CI]*
Squat 1RM	Weeks 1-8 (Training)	0.79 ± 0.40 [b] Moderate	0.44 ± 0.39 [a] Small	-0.09 ± 1.70 Unclear
	Weeks 10-12 (Maintenance)	0.05 ± 0.09 Trivial	0.01 ± 0.38 Unclear	0.22 ± 0.81 Unclear
	Weeks 1-12	0.67 ± 0.48 [b] Moderate	0.42 ± 0.39 [a] Small	0.13 ± 1.51 Unclear
Step-up 1RM (average of left and right legs)	Weeks 1-8 (Training)	0.22 ± 0.37 Small	0.63 ± 0.17 [c] Moderate	0.29 ± 0.75 Unclear
	Weeks 10-12 (Maintenance)	0.07 ± 0.34 Trivial	0.11 ± 0.23 Trivial	-0.38 ± 0.15 [b] Small
	Weeks 1-12	0.27 ± 0.39 Small	0.74 ± 0.38 [b] Moderate	-0.09 ± 0.77 Unclear

1RM = one repetition maximum. ES ± 90% CI = effect size ± 90% confidence interval. ES classified according to: <0.2 as trivial; 0.2-0.6 as small; 0.6-1.2 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). %Likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: a >75% as “likely”; b >95% as “very likely; and c >99.5% as “almost certainly”. Baseline adjustments: comparisons were adjusted due to the Step-up being the stronger group at baseline

Table 10.6 The magnitude of change in strength, between the groups for each training cycle.

	Bilateral vs Unilateral groups		Bilateral vs Comparison groups		Unilateral vs Comparison groups	
	1RM Squat	1RM Step-up (Average of left and right)	1RM Squat	1RM Step-up (Average of left and right)	1RM Squat	1RM Step-up (Average of left and right)
Weeks 1-8 (Training)	-0.34 ± 0.55 Unclear	0.41 ± 0.36 [a] Small [U]	0.90 ± 1.14 [a] Moderate [B]	-0.28 ± 0.53 Small [B]	-0.42 ± 1.22 Unclear	-0.16 ± 0.61 Unclear
Weeks 10-12 (Maintenance)	-0.04 ± 0.35 Unclear	0.03 ± 0.34 Unclear	1.01 ± 1.06 Moderate [B]	-0.32 ± 0.24 [a] Small [B]	0.15 ± 0.60 Unclear	-0.37 ± 0.19 [a] Small [U]
Weeks 1-12	-0.26 ± 0.60 Unclear	0.47 ± 0.47 [a] Small [U]	0.93± 1.13 Moderate [B]	-0.54 ± 0.56 [a] Small [B]	-0.24 ± 1.09 Unclear	-0.54 ± 0.66 [a] Small [U]

1RM = one repetition maximum. ES ± 90% CI = effect size ± 90% confidence interval. ES classified according to: <0.2 as trivial; 0.2-0.6 as small; 0.6-1.2 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). %Likelihood of exceeding the smallest important ES of 0.2 and qualitative descriptor: a >75% as “likely”; b >95% as “very likely; and c >99.5% as “almost certainly”. Baseline adjustments: comparisons were adjusted due to the Step-up being the stronger or faster group at baseline. B = performance adaptation benefits Bilateral group; U = performance adaptation benefits Unilateral group.

DISCUSSION

This investigation sought to explore the specificity and transfer of isoinertial strength training between bilateral and unilateral movements. In accordance with the principle of specificity, both the bilateral and unilateral training groups demonstrated moderate improvements in their trained movement. Additionally, both groups also demonstrated small improvements in the non-trained movement. The primary finding being that the underlying physiological and biomechanical stimuli of neuromuscular adaptation can be developed bilaterally or unilaterally, and may be exhibited to a lesser extent in performance of the non-trained variant.

It has been suggested that the closer the mechanical specificity of a training exercise to a performance, the greater the transfer of performance gain (528, 565, 590). For example, lower body maximal strength is often assessed by a 1RM squat, and strength training usually involves squatting (32, 115). The results of this study support this concept as both groups showed the greatest improvement in their trained exercise (Figure 10.5, Table 10.5) and these improvements are in line with those previously reported in bilateral and unilateral training (115, 511).

The phenomena of transfer is dependent upon mechanical specificity (contraction type, contraction velocity and joint angle) between the training stimulus and the performance; the closer the two, the greater the transfer (528, 565). In the current study both groups showed small strength increases in their non-trained movement indicating a level of transfer between the exercises (Table 10.5). These findings are similar to research in bilateral and unilateral training investigations (389, 511). Notably, the improvements in strength of both groups in both exercises highlights the importance of the underlying physiological and biomechanical demands of an exercise driving adaptation, and not the outward appearance. This has practical implications where strength and conditioning coaches may experience constraints with equipment (i.e. in the case of travel or large athlete numbers) or the athlete (through acute or chronic injury) where the substitution or incorporation of a similar exercise can yield transfer benefits.

Neuromuscular differences have been reported between bilateral and unilateral movements (9, 386). This is attributed to the greater stability requirements of the unilateral exercise and the neuromuscular control required for efficient performance (386). The results of this study suggest that strength improvements from a unilateral exercise can improve strength in a bilateral movement. An advantage of unilateral exercises may be in the development of coordination and stabiliser musculature that may not be sufficiently stimulated in stable, bilateral movements (386). For example, decreasing the stability of an exercise can result in increased balance requirements, antagonist recruitment and co-contraction, and trunk/hip activation levels (9, 22, 474). Additionally, unilateral exercises require a lower total external load which would be valuable in unloading anatomical structures such as the spine (263, 421). However, the increased requirement for stability has been shown to decrease the force output of agonists and when combined with the lower external resistance possible, suggests that unilateral exercises are perhaps less effective for the development of maximal strength (376, 386). However, the results from this investigation support previous work (511) and suggest that unilateral exercises can effectively develop strength and also transfer strength to bilateral performance (Table 10.6). However, a small difference (0.41 ± 0.36) existed between the improvement in step-up strength, in favour of the unilateral group. This suggests that training the unilateral exercise facilitated an adaptation necessary for step-up performance that the bilateral group did not experience. Whether the strength development benefits of the step-up exercise transfers to sprint and change of direction performance requires further investigation.

A unique feature of this investigation was the presence of a short maintenance phase, representative of short-term in-season phases in elite team sports often necessitated by competition, recovery and travel. As a result, the opportunities for physical development are limited, shifting to a focus of maintaining capacity developed during the pre-competition phase. Previous research has reported that one resistance training session per week is sufficient to maintain strength (14, 24, 224, 467). In the current investigation, although much shorter in duration than the previously mentioned studies, both intervention groups remained relatively unchanged in their trained exercise (trivial ES changes) during the three-week period of only one resistance session per week. This suggests that in phases of competition or travel where strength training may be limited to one session per week, unilateral or bilateral resistance training is sufficient to maintain strength for short periods.

Whilst rigorous planning was implemented, in a training study involving "real-world" athletes, it is not possible to control every aspect. The following limitations should be considered when interpreting the results. First, complexity exists in balancing workloads between groups which has been identified in previous research attempting to fairly observe the influence of bilateral and unilateral training which may result in unequal training stimulus between the intervention groups (363, 511). Additionally, a 90° knee flexion angle was used to compare bilateral and unilateral exercises and future research may investigate angle greater than 90° (80). Finally, due to the squad nature of the group training it was not possible to blind participants and coaches from the training interventions.

The results of this study demonstrate that lower body strength can be developed using bilateral or unilateral means and that strength can be transferred between movements as indicated by the degree of change in the non-trained exercise in the current study. The findings of this study support the use of unilateral or bilateral exercises for improved strength development where muscular intensity is matched. Further studies should ascertain the transfer to measures of sport performance such as speed and change of direction.

PRACTICAL APPLICATIONS

Lower body strength can be developed using unilateral (step-up) or bilateral (squat) resistance training and expressed in the non-trained variation. Coaches may be able to confidently substitute unilateral exercises for bilateral for lower body strength development. Practically, this may assist the development and maintenance of strength when coaches are limited by equipment (ie. large athlete numbers or training facility limitations). The use of unilateral exercises during periods of travel may also benefit athletes by maintaining strength. Furthermore, the lower external loading utilised in unilateral exercises may beneficially unload anatomical structures which may benefit athletes with acute or chronic injury who cannot tolerate large external loads. Additionally, the integration of the step-up in a periodised plan may benefit further strength development and the improvement of advantageous secondary neuromuscular stabilisers.

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