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ABSTRACT

This study explored the effects of an 8-week repeated backward running training (RBRT) programme on measures of physical fitness in youth male soccer players. Youth male soccer players were randomly allocated into a RBRT group (n=20; 13.95±0.22y) or a control group (CG; n=16; 14.86±0.29y). The CG continued normal soccer training, while the RBRT group replaced some soccer drills with RBRT twice per week. Within-group analysis revealed that RBRT improved all performance variables (Δ-9.99% to 14.50%; effect size [ES] = -1.79 to 1.29; p≤0.001). Meanwhile, trivial-to-moderate detrimental effects on sprinting and change of direction (CoD) speed (Δ1.55% to 10.40%; p≤0.05) were noted in the CG. The number of individuals improving performance above the smallest worthwhile change ranged from 65-100% across all performance variables in the RBRT group, whereas <50% in the CG reached that threshold. The between-group analysis indicated that the RBRT group improved performance on all performance tasks more than the CG (ES = -2.23 to 1.10; p≤0.05). These findings demonstrate that substituting part of a standard soccer training regimen with RBRT can enhance youth soccer players' sprinting, CoD, jumping, and RSA performance.

Keywords: musculoskeletal and neural physiological phenomena, human physical conditioning, movement, muscle strength, youth team sports.

INTRODUCTION

Soccer players' athletic qualities such as sprinting, jumping, change of direction (CoD) speed and repeated sprint ability (RSA) are major determinants of performance (32, 33), and largely influence soccer match performance in young players (32 33, 34). Indeed, elite soccer players are characterised by high levels of muscular strength, speed, and derivatives thereof (i.e., acceleration, sprinting, jumping, CoD, and RSA), when compared to sub-elite soccer players (32, 33, 34). While these athletic qualities naturally improve in youth athletes due to growth and maturation (12), the development of these traits can be further enhanced through focused training interventions (18).

To develop athletic qualities in youth soccer players, both specific and non-specific training methods can be used (19). The principle of training specificity suggests that to achieve the best possible outcome, a training modality should be closely related to the neuromuscular and physiological characteristics of the particular athletic task it is intended to enhance (20). This principle is substantiated by findings that specific training methods, which have high biomechanical and physiological resemblance to soccer-related tasks, and are produced through shared locomotive neural networks (13), demonstrate a high transfer to athletic movements such as sprinting, CoD ability, jumping and RSA (19,36). Whilst specific training methods are commonly thought to imitate athletic tasks (7,49), there is emerging evidence that performing athletic movements in reverse can also stimulate positive adaptations, enhancing the performance of movements executed in forward directions (43). In particular, backward running (BR), has been proposed to be a training method that can improve forward running (FR) (45) due to both tasks originating from the same locomotive central pattern generators (21).

Similar to FR, BR is a movement strategy that occurs in sporadic bursts during soccer play (31). Indeed, elite soccer players may spend 3-4% of the match in a BR motion with FR movements representing 0.9-1.4% only (31, 43). According to the same authors (31, 43), top-class soccer players (ranked 1–10 on the official FIFA list) spend significantly more time in BR motion compared to moderately ranked soccer players (ranked higher than 20 on the official FIFA list) (3.7±0.3% vs. 2.9±0.2%, respectively). This shows that BR is an important locomotor parameter during soccer games. Compared to FR, BR is characterised by an increased reliance on isometric and concentric muscular actions (9), decreased elastic utilization (8,38), and greater muscle activation in the lower limbs (17,48). Given the unique demands of BR on musculotendinous functioning, it has been implemented as a training protocol to enhance athletic qualities such as sprinting performance (44), CoD speed (42), and jumping height (44). Besides improving these relatively high-velocity movements related to maximal neuromuscular capabilities, BR training has also been found to promote positive adaptations in cardiovascular fitness (35,41). Since BR results in approximately 28-35% greater energy expenditure compared to FR at similar running velocities (11,38), it may be a particularly effective method for stimulating positive adaptations in athletic qualities that are dependent on cardiorespiratory capabilities (45), such as RSA (4). However, while previous findings indicated that BR training can improve running economy (35) and oxygen consumption (41), there are no empirical investigations as of yet on the effectiveness of BR training on RSA.

In addition, readers should be cognisant that all previous training studies which utilised BR, implemented either steady-state low-velocity running (35,41) or maximal effort BR sprinting with work-to-rest ratios >1:3 (42,44). Furthermore, only the study by Uthoff and colleagues (44) explored the effects of BR training on speed and power measures in adolescent male athletes (age=14.59 ± 0.29), and no studies have explicitly investigated the effects of repeated BR training (RBRT) on physical fitness capabilities in youth male soccer players. This highlights a dearth of empirical evidence on the utility and effectiveness of RBRT using maximal efforts, with minimal rest, on youth soccer players' physical fitness. Accordingly, this study aimed to investigate the effects of an 8-week RBRT program on youth male soccer players' linear (5-, 10-, and 20-m) and CoD (505 test) sprint times, countermovement jump (CMJ) height, standing long jump (SLJ) distance and RSA for both fastest (RSA_{best}) and total (RSA_{total}) time. We hypothesised that, compared to regular soccer training, substituting parts of a standard soccer training regimen with RBRT would induce larger improvements in measures of physical fitness in youth male soccer players (43).

METHODS

Experimental approach to the problem

A randomized controlled trial was undertaken to study the effects of an 8-week RBRT programme on measures of physical fitness in youth male soccer players. The training programme was conducted during the in-season period of the year 2021 (February-March). All participants were habituated to the physical fitness tests from their routine physical preparation programme prior to testing. All tests were scheduled at least 48 hours after the last executed training session or soccer match and were conducted at the same time of day (7:30–9:30 AM) under the same environmental conditions (30–33° C, no wind). Testing occurred over three days with linear sprint speed and CoD speed testing conducted on the first day, jump testing on the second day, and RSA on the third day. Youth players were assessed before and after an 8-week RBRT programme. No specific nutritional supplements were taken by the players. During testing, participants were instructed to follow their normal consumption of food and fluids. In addition, the players were told to abstain from physical exercise for one day before testing.

Participants

Thirty-six male youth soccer players from a regional soccer team were randomly assigned to an RBRT group (n=20) or a control group (CG, n =16). The anthropometric characteristics of both groups are displayed in Table 1. The assigned groups were determined by a chance process (a random number generator on a computer) and could not be predicted. This procedure was established according to the "CONSORT" statement (http://www.consort-statement.org). Figure 1 displays a CONSORT diagram of the levels of reporting and participant flow. The participants had 6.0 ± 1.3 years of systematic soccer competition and training, involving five training sessions (80-90 min each) per week and a competitive game on weekends. Athletes who missed more than 20% of the total training sessions and/or more than two consecutive sessions were excluded from the study (32). Biological maturity status was estimated using the maturity offset (MO) method. The MO was calculated by predicting age at peak height velocity using the estimation equation established by Mirwald et al (30). MO = -9.236 + (0.0002708·leg length and sitting height interaction) – (0.001663·age and leg length interaction) + (0.007216·age and sitting height interaction) + (0.02292·weight by height ratio*100).

Figure 1 near here

Table 1 near here

All players met the following inclusion and exclusion criteria: (i) continuous soccer training over the past three months with no serious musculoskeletal injuries (i.e., no more than one session missed), (ii) absence of potential medical problems that could compromise participation or performance in the study, and (iii) no lower-extremity surgery in the past two years before the study. All procedures were approved by the Institutional Review Committee for the ethical use of human subjects at ****blind to reviewers****. Written informed parental consent and participant assent were obtained before the start of the study. All participants and their parents/legal representatives were informed about the experimental protocol and its potential risks and benefits before the commencement of the research project. Participants were permitted to withdraw from the study at any time and without having to provide a reason for doing so.

Training Programme

Both groups participated in the same regular soccer-specific training programme over the 8-week intervention period. Soccer training sessions for both groups included fast footwork drills, technical skills and moves, position games and tactical games. Both the RBRT group and the CG completed 40 soccer training sessions during the intervention period and competed in seven matches.

Repeated backward sprint training programme

The RBRT sessions were integrated into the regular soccer training routine of the intervention group after their standard warm-up, replacing 15 to 20 minutes of low-intensity soccer drills, on Tuesdays and

Thursdays, over 8 weeks, on an artificial grass soccer pitch (Table 2). Coaching cues (i.e., “slight lean of the chest forward”, “use similar arm action to forward running”, and “high heel recovery of the swing leg”) similar to those used by Uthoff et al. (44) were used to reinforce the BR techniques. Players were instructed to exert maximal effort, across all repetitions, by covering the prescribed running distance (20-m) as fast as possible. Overall, players performed between two and four sets with seven repetitions in each set. The inter-set and inter-repetition rests were 4 minutes and 20 seconds, respectively. After the RBRT session, the players completed the remainder of their regular soccer training.

*****Table 2 near here*****

Linear sprint speed time

Twenty-meter linear sprint performance was assessed at 5-, 10-, and 20-m intervals using a single beam electronic timing system (Microgate SRL, Bolzano, Italy). Participants started in a standing split stance position with their lead foot 0.3 m behind the first infrared photoelectric gate, which was placed 0.75 m above the ground to ensure that it captured trunk movement and avoided false signals through limb motion. In total, four single-beam photoelectric gates were used. No rocking or false steps were permitted before starting. The between-trial recovery time was three minutes. The best performance out of two trials was used for further analysis. The intra-class correlation coefficients (ICCs) for test-retest reliability were 0.91, 0.93, and 0.90 for 5-, 10- and 20-m respectively.

505 change of direction speed time

The 505 CoD test was administered using the protocol previously outlined by Negra et al. (33) using an electronic timing system (Microgate, Bolzano, Italy). Players assumed a standing split stance position 10-m from the start line, ran as quickly as possible through the start/finish line, pivoted 180° at the 15-m line indicated by a cone marker, and returned as fast as possible through the start/finish line. To ensure proper execution of the test, a researcher was positioned at the turning line and if the participant changed direction before reaching the turning point, or turned off the incorrect foot, the trial was disregarded and reattempted after the recovery period. A between-trial rest period of three minutes was provided. The best performance out of two trials was used for further analysis. The ICC for test-retest trials was 0.95.

Countermovement jump height

For this test, participants started from an upright standing position and performed a fast downward movement by flexing the knees and hips before rapidly extending the legs and performing a maximal vertical jump. During the test, participants were instructed to maintain their arms akimbo. Jump height was recorded using a floor-level optoelectric system (Optojump, Microgate, SRL, Bolzano, Italy). A rest period of one minute was allowed between trials. Participants’ best performance out of three trials was retained for further analysis. The ICC for test-retest reliability was 0.92.

Standing-long-jump distance

During the bilateral SLJ test, participants stood with their feet shoulder-width apart and toes behind a starting line. On the command of “ready, set, go”, participants performed a fast flexion of the legs and downward movement of the arms, before jumping as far as possible in a horizontal direction. Participants were instructed to land with both feet at the same time and were not allowed to fall forward or backward. The horizontal distance between the starting line and the position of the heel of the rear foot upon landing was recorded using a tape measure to the nearest 1-cm. A between-trial rest period of one minute was allowed. The best of three trials was recorded for further analysis. The ICC for test-retest reliability was 0.91.

Repeated sprint ability

The RSA test was assessed via the same photocell system used for the linear speed and 505 CoD tests (Microgate, Bolzano, Italy). Immediately after a standardised warm-up, participants completed a preliminary single shuttle-sprint test (20+20 m with 180° CoD). The first trial provided the criterion score for the actual shuttle-sprint test (34). Participants then rested for five minutes before starting the RSA test. During the first sprint, participants had to achieve at least 97.5% of their criterion score, otherwise, they rested for five minutes and then restarted the test (34). We used such an approach to determine if participants adopted a coping strategy for performance. Of note, all participants attained their criterion score during the first sprint. All performed six 20-m shuttle sprints with 180º turns, separated by 25 seconds of passive recovery (34). Three seconds prior to the commencement of each sprint, players were asked to adopt the ready position using a split stance, with their front foot 0.3 m behind the starting line, until the next start signal. From the starting line, they sprinted for 20-m and touched the second line with one foot before performing a 180° CoD and returning to the starting line as quickly as possible. Participants were instructed to complete all sprints as fast as possible. The RSA_{best} and RSA_{total} were determined. Due to the fatigue induced by the test, only one maximal attempt was made i.e., no ICC was calculated.

Statistical Analyses

The normality of all variables was tested and confirmed using the Shapiro-Wilk test. The homogeneity of variance was assessed using Leven’s test. Within-group training-related effects from pre- to post-training were analyzed using paired sample t-tests. A one-way analysis of variance was used to assess the training-related effects between the groups on the change score (mean difference from pre-training to post-training). Additionally, effect sizes (ES) and percentage changes were calculated to determine the magnitude of the performance change both within- and between-group. The ES was calculated by dividing the mean change in performance by the pooled standard deviation (SD) of the sample scores (24) and classified as trivial (<0.20), small ($0.20 \leq ES \leq 0.59$), medium ($0.60 \leq ES \leq 1.19$), and large ($ES \geq 1.20$) (23). The smallest worthwhile individual change (SWC) was calculated on the pooled standard deviation of pre-training performance scores for both groups and converted to a percentage for each performance variable. The worthwhile changes were considered small (0.2 * SD), moderate (0.6 * SD), and large (1.2 * SD) (22,23). Note that the SWC for sprinting, 505 CoD, and RSA performance is negative to reflect that decreases in times are associated with performance improvements. Test-retest reliability was assessed using the $ICC_{(3,1)}$. Data were presented as group means and SD. The level of significance was set a priori at $p \leq 0.05$ and 95% confidence limits were used. Data analyses were conducted using Microsoft Excel (version 22.04; Microsoft, Seattle, WA, USA) and SPSS 24.0 program for Windows (SPSS, Inc, Chicago, IL, USA).

RESULTS

All participants (n=36) received the treatment conditions as allocated. The adherence rate to training was 96% for both groups. None of the participants reported any training- or test-related injuries. Within-group changes from pre- to post-training and between-group differences in the performance tests for the RBRT and CG groups are displayed in Table 3. The within-group analysis found that RBRT elicited significant improvements in all performance variables (Δ-9.99% to 14.5%; d = -1.79 to 1.29; $p \leq 0.001$). Meanwhile, the CG significantly decreased sprinting and 505 CoD performance (Δ1.55% to 10.40%; $p \leq 0.05$) with effects ranging from trivial-to-moderate. For the other measures of physical fitness, no significant changes were observed in the CG (p>0.05).

*****Table 3 near here*****

In terms of individual responses, Figure 2 illustrates the individual percentage changes relative to small, moderate, and large worthwhile changes detected for the RBRT group and CG. The RBRT group had the highest relative number of individual responses above the SWC for 5- (95%), 10- (75%), and 20-m (65%), 505 CoD (85%), CMJ (100%), SLJ (95%), RSA_{best} (80%) and RSA_{total} (80%). Whereas only 25% to 50% of the participants of the CG improved performance above the SWC for any of the performance tests.

*****Figure 2 near here*****

The one-way ANOVA on the change scores revealed a significant difference between groups for all performance tests ($p \leq 0.001$). Compared with the CG, significant favorable differences were found for the RBRT group for all sprinting distances, 505 CoD, CMJ height, SLJ distance, and RSA performance (d = -2.23 to 1.10).

DISCUSSION

The present study is the first to explore the effects of performing RBRT on measures of physical fitness in male youth soccer players. Our findings demonstrated that substituting part of a standard soccer training regimen with RBRT improved short sprint performance, 505 CoD time, jumping ability, and RSA. Regular soccer training on the other hand impaired sprinting and CoD performance with no effects on the other physical fitness parameters. These results are important for researchers and practitioners, given the lack of published literature on the effects of RBRT on measures of physical fitness in youth athletes.

Sprinting ability is critical for success in soccer with sprinting activities frequently performed prior to decisive moments in games such as scoring a goal (15). The findings from our study revealed that RBRT resulted in moderate to large within-group improvements in short sprint performance over distances up to 20-m (5-m: absolute change=0.11; ES=-1.79 [-9.99%]; 10-m: absolute change=0.05; ES=-0.74 [-2.39%]; 20-m: absolute change =0.07; ES=-0.75 [-2.24%]). A similar trend was observed in our between-group analysis with significantly larger training-related increases in 5-, 10- and 20-m performance (ES=-2.23, -1.24, and -0.70, respectively) in the RBRT group compared to the CG. Indeed, 65 to 95% of the RBRT group improved sprint performance over all of the measured distances to a level that exceeded the SWC compared to only 25 to 31% in the CG. These results are in agreement with those of Uthoff and colleagues (44) who demonstrated that eight weeks of BR training resulted in moderate-to-large within-group improvements (-5.01% to -7.47%; ES = -1.04 to -1.56) in forward sprint performance in male youth athletes and moderate-to-large performance gains (ES = -1.05 to -1.59) when compared to a CG performing normal physical education training. Likewise, Negra and colleagues (34) reported a moderate improvement in 10-m (0.08 s; ES=0.68) and 20-m (0.17s; ES= 0.67) sprint performance after nine weeks of a forward repeated sprint training (FRST) programme, with and without CoD in male youth soccer players aged 16 years. The present findings suggest that performing RBRT during the in-season period can induce preferential adaptations in short sprint performance in a forward direction in male youth soccer players, findings that are reinforced by previous literature (34). However, it must be highlighted that, similar to other BR training research (44), this study found that RBRT resulted in greater adaptations during short accelerative tasks (i.e., 5-m: -9.99%) relative to long accelerative tasks or maximal velocity sprints (i.e., 20-m: -2.24%). These findings are further supported by the average absolute changes in performance and individual responses of participants. Indeed, the absolute changes in performance for 5-, 10-, and 20-m were 0.11, 0.05, and 0.07 s, respectively, with the highest number of individual responses above the SWC observed for 5- (95%) followed by 10- (75%) and 20-m (65%). These findings support the result that BR preferentially transfers to early phases of sprint performance in youth male athletes. Further, compared to forward running, BR is achieved through higher step frequencies and lower step lengths (43, 44, 45). Therefore, improvements in sprint performance could mainly be attributed to alterations in steps kinematics which are representative of early accelerative sprinting (i.e., 10-m) (47). Overall, an absolute change in sprint performance equal to the above mentioned values would be indicative of a meaningful improvement in most participants. Of note, results indicated decreased sprint performance across 5-, 10-, and 20-m distances in the CG. This may be associated to non-optimal training load associated with regular soccer practice (26). This further support the need to integrate other training methods, such as RBRT, to stimulate positive sprint performance adaptation in youth male soccer players.

Change of direction ability is a key determinant of high-performance play in the sport of soccer (29). Our results showed moderate (absolute change = 0.15s; ES=-1.12 [5.67%]) within-group improvements in the 505 CoD test after RBRT, and large (ES=-2.16) improvements compared to the CG. Interestingly, 85% of the participants of the RBRT group improved 505 CoD performance to a level that was greater than the SWC with none in the CG. This suggests that an absolute change equal to 0.15s after eight weeks of RBST is indicative of a meaningful improvement in most participants. These findings are in agreement with results from previous research that found 3.00 to 3.37% improvements in 505 CoD performance in ~18-20-year-old female netball athletes after six weeks of BR training (42). Furthermore, the results of the current study align with previous reports that nine weeks of repeated forward sprint training (FRST) can be used to induce large gains in 505 CoD performance in male youth soccer players (34). Similarly, Beato et al. (2) observed moderate (ES=0.62) improvements in the 505 CoD test after eight weeks of FRST, combined with CoD, in elite young male soccer players. While FRST can be used to improve CoD ability in youth male soccer players, the greater coordination demands associated with BR (27) may help to provide a unique training stimulus to further develop this athletic quality through adaptations towards being able to position oneself to change directions more effectively (i.e., more optimal movement policies) (1). While the unique responses to BR such as a reliance on isometric and concentric muscular action (9) and large magnitudes of muscle activation in the lower limbs (17,48) are considered important elements during CoD (40), a direct comparison between repeated backward versus RFST on CoD ability needs to be conducted to support this position. Of note, CoD performance decreased in the CG. Similar to sprint performance, regular soccer training alone does not seem to provide adequate training stimuli to trigger positive adaptations in CoD performance in male youth soccer players. Although the underlying mechanisms of such sub-optimal CoD response are unclear, unchanged or even reduced linear and non-linear sprinting performances in soccer players (26) (and other athletes) have been associated with non-optimal sport-specific stimuli, e.g. predominance of *aerobic* training dose (46). Further, such reduction may be particularly notable during the in-season (as in our study), due to limited time for strength and conditioning, with more focus on technical-tactical aspects. Therefore, the integration of RBRT during the in-season period of the year is advisable to induce positive adaptive responses in CoD performance in youth male soccer players.

Jumping performance can be used to discriminate between elite and non-elite youth soccer players (10). The results of our study revealed that RBRT yielded large within-group enhancements for both CMJ (absolute change = 4.4 cm; ES=1.19 [14.5%]) and SLJ (absolute change = 17.8 cm; ES=1.29 [9.38%]) performance, and moderate (ES=1.10, and 1.05, respectively for CMJ and SLJ) improvements compared to the CG. These changes are greater than the moderate (9.9%) improvements in CMJ height previously reported following eight weeks of progressive BR training (44) and provide the first insight into the effects of BR training on horizontal jump performance. Notably, ≥95% of the participants in the RBRT group improved both CMJ and SLJ performance above the SWC, while only about half of the CG experienced increases above that level. This suggests that absolute changes of 4.4cm in CMJ and 17.8cm in SLJ after RBST represent meaningful gains in the vast majority of participants. Though no previous direct comparisons between RBRT and RFRT exist, the relative improvements in CMJ following RBRT in the current study are over twice as large as those previously found following repeated forward running shuttle sprints (7.04%) in a group of 14.5-year-old elite soccer players (5). Since BR relies predominantly on isometric and concentric actions of the contractile tissues to produce movements (8,9), this direction of running may lead to muscle action-specific strength improvements which transfer to athletic movements that depend primarily on concentric muscle functioning of the quadriceps, such as vertical and horizontal countermovement jumps (45). While interesting to suggest, the veracity of this theory still requires further investigations to fully support a causal link between lower body muscle actions and adaptations to jumping ability following BR training.

The ability to repeatedly produce maximal sprint efforts with minimal recovery time is necessary for highly-trained youth soccer players due to the nature of the bouts of intermittent activity that characterise match play and training (6). The current RBRT intervention induced moderate within-group improvements in RSA_{best} (absolute change = 0.25s; ES=-1.01 [-3.19%]), and RSA_{total} (absolute change = 1.3s; ES=-0.94 [-2.76%]) and moderate (ES=-1.11 and -0.77, respectively for RSA_{best} and RSA_{total}) increases in these metrics relative to the CG. Furthermore, 80% of the RBRT group improved both RSA_{best} and RSA_{total} above the SWC, suggesting that alteration in performance equal to the above-mentioned absolute change values represent meaningful improvements in most participants. These results are similar to the moderate improvements in RSA_{best} (-2.90%) and RSA_{mean} (-2.61%) observed in 14-year-old elite male soccer players following repeated forward sprint training in a previous investigation (5). Together, these findings suggest that RBRT can result in positive meaningful changes in RSA in youth soccer players which are comparable to the adaptations seen after forward sprint training. Indeed, performing repeated sprints backward may constitute a more cost-effective means to improve RSA since BR exerts a high metabolic demand on an individual (16,48), ultimately leading to approximately 28% greater energy expenditure compared to FR at similar relative intensities (11). However, further research is necessary to support this position given the lack of direct comparisons between programmes of volume-equated repeated backward and forward running training.

This study comes with some limitations that the reader should be aware of. Firstly, it was limited to youth male soccer players meaning it may have low applicability to a youth female population given the growth and maturational difference between the sexes during adolescence. Secondly, save for accounting for the number of sessions completed, we did not monitor training load throughout the intervention by using external and/or internal measures. Thirdly, no direct physiological (e.g., electromyography) or biomechanical (e.g., vertical ground reaction force) measures were conducted in the study. On this basis, future research should include more direct kinetic and kinematic analyses on the effects of volume-equated repeated backward versus forward sprint training on measures of strength, speed, and RSA in male youth soccer players.

To sum up, this randomised controlled trial demonstrates that male youth soccer players, who are already participating in a demanding training schedule, can make further gains in physical fitness if they replace a part of their standard regimen with an in-season eight weeks twice-weekly programme of RBRT. While the exact mechanisms underpinning these adaptations remain somewhat ambiguous, the novel isometric and concentric-focused movement strategy associated with BR appears to produce unique neuromuscular and metabolic responses which transfer particularly well to the early acceleration phase of forward sprinting, 180° CoD, slow stretch-shortening cycle jumping (i.e., CMJ and SLJ) and RSA in youth male soccer players.

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Authors' contributions

YN collected the data, analysed the data, and wrote the manuscript; AU analysed the data and wrote the manuscript; SS collected the data and wrote the manuscript; RRC wrote the manuscript; JM and HC conceived the study, and wrote the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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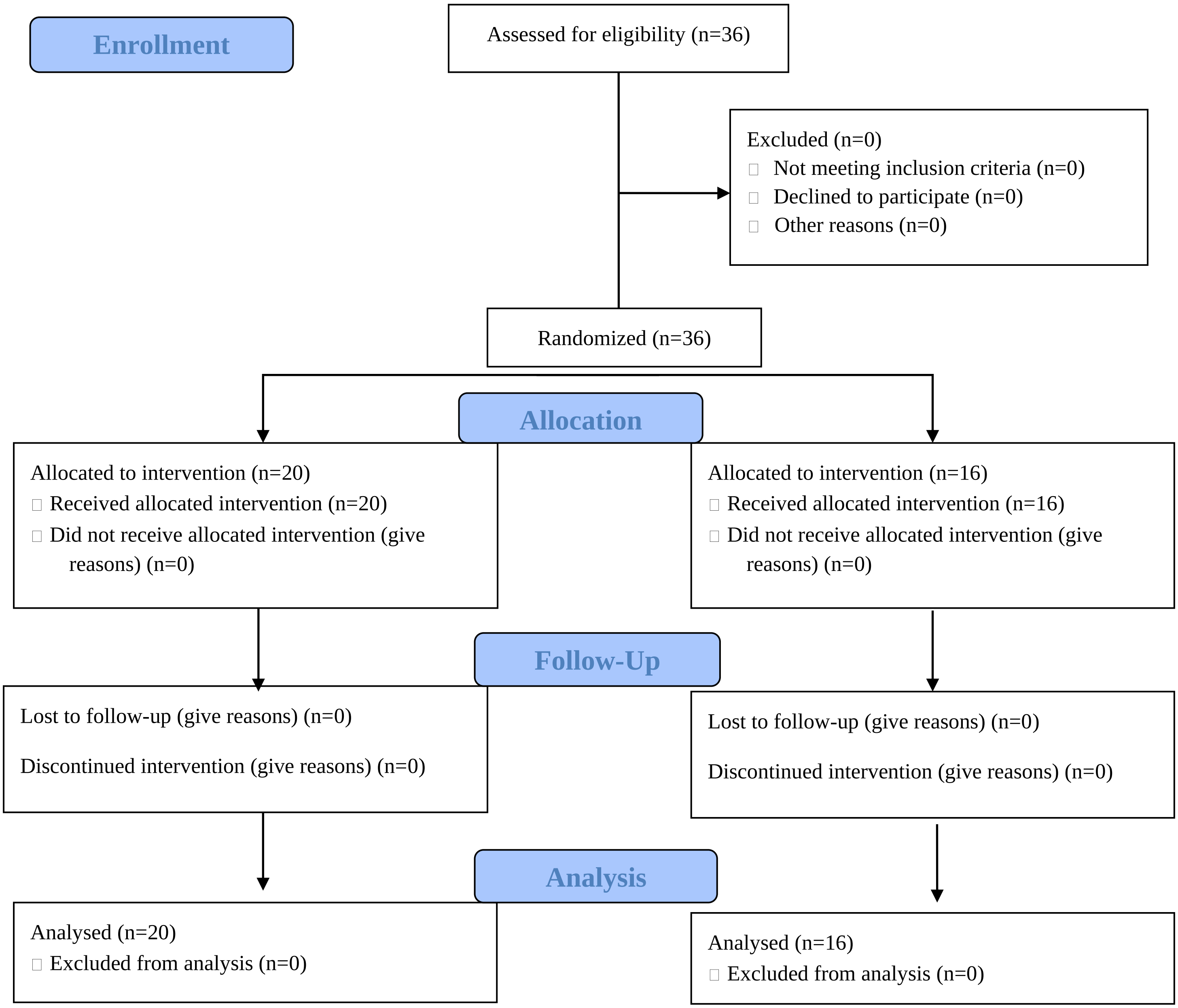

Figure 1. The diagram (The CONSORT: Consolidated Standards of Reporting Trials) includes detailed information on the interventions received.

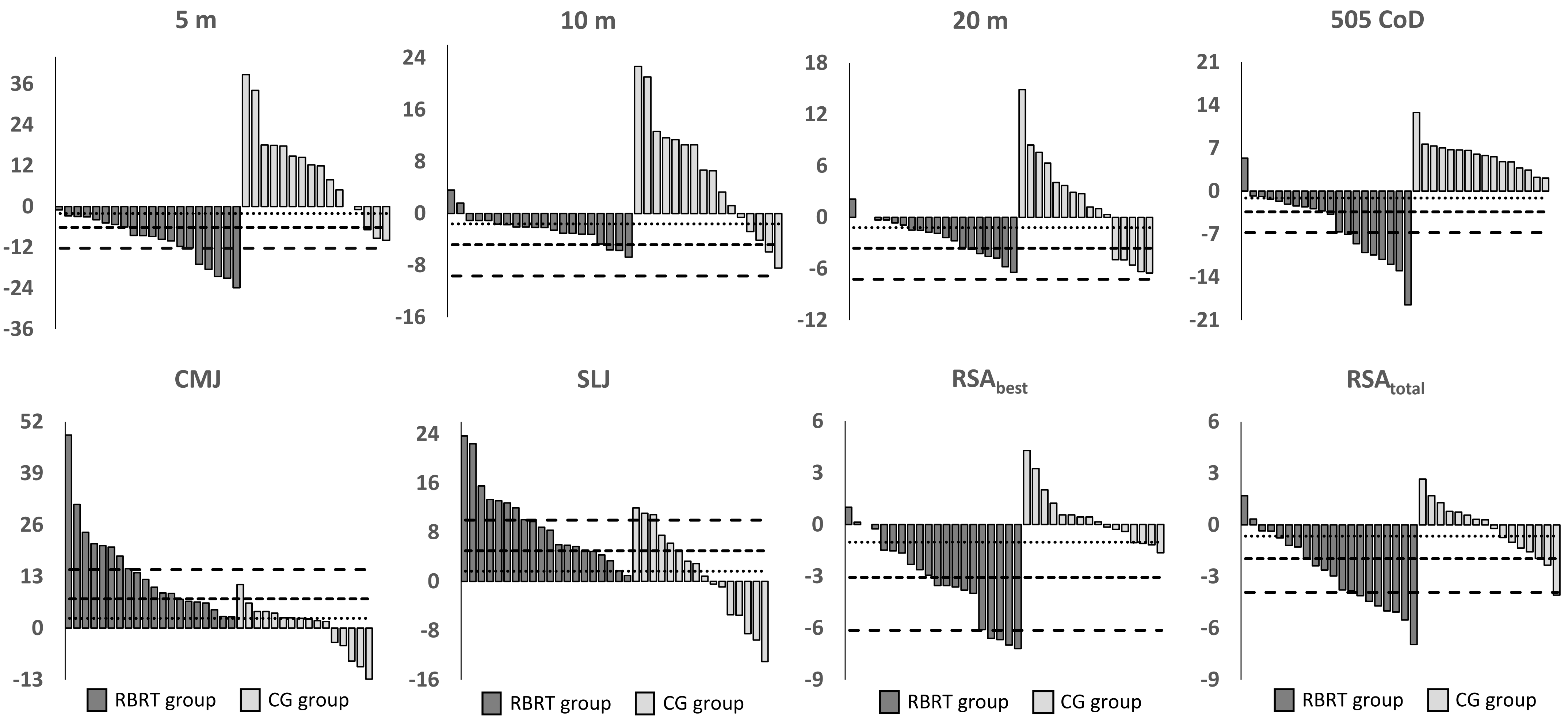

Figure 2. Individual relative percentage change from pre- to post-intervention in repeated backward running training group (RBRT) group and control group (CG). SWC = smallest worthwhile change pre SD * 0.2); ---- MWC = moderate worthwhile change (pre SD * 0.6); — — - LWC = large worthwhile change (pre SD * 1.2). 5 m, 10 m, 20 m: linear sprints; CoD: change of direction; CMJ: countermovement jump height; SLJ: standing long jump; RSA: repeated sprint ability.

Table 1. Anthropometric characteristics of the included participants.

	RBRT group (n= 20)	CG (n= 16)
Age (years)	13.95±0.22	14.86±0.29
Height (m)	166.49±8.91	170.31±3.82
Body mass (kg)	50.96±6.82	56.49±5.09
Maturity offset (years)*	-0.62±0.61	0.14±0.63

Notes: Data are presented as means and standard deviations; RBRT= repeated backward running training; CG = control group; *: as years from peak height velocity.

Table 2. Repeated backward running training program.

Week 1	3 × 7 × 20*
Week 2	3 × 7 × 20
Week 3	3 × 7 × 20
Week 4	2 × 7 × 20
Week 5	4 × 7 × 20
Week 6	4 × 7 × 20
Week 7	4 × 7 × 20
Week 8	3 × 7 × 20

*: denotes sets × repetitions × distance (m).

Table 3. Descriptive performance testing results for RBRT and CG groups, including within-group changes from pre-training to post-training and between-group differences in the mean changes.

	Group	Pre (μ ± SD)	Post (μ ± SD)	Post-Pre % Difference (95% CL)	Post-Pre Training Effect Size (95% CL)	Difference RBST - CG (μ ± SE)	RBRT – CG Effect Size (95% CL)
5m sprint (s)	RBST	1.07±0.06	0.96±0.06	-9.99 (-13.0 to -6.99) †	-1.79 (-2.52 to -1.06)	-0.20±0.04 †	-2.23 (-3.06 to -1.39) ^{B}
	CG	0.96±0.11	1.04±0.07	10.4 (3.51 to 17.3) *	0.91 (-0.39 to 1.06)		
10m sprint (s)	RBRT	1.89±0.06	1.84±0.06	-2.39 (-3.42 to -1.32) †	-0.74 (-1.38 to -0.10)	-0.14±0.04 †	-1.24 (-1.96 to -0.52) ^{B}
	CG	1.70±0.15	1.79±0.09	6.03 (1.55 to 10.5) *	0.73 (-0.45 to 0.98)		
20m sprint (s)	RBRT	3.31±0.11	3.24±0.09	-2.24 (-3.21 to -1.28) †	-0.75 (-1.39 to -0.11)	-0.11±0.05 *	-0.70 (-1.37 to -0.02) ^{B}
	CG	3.10±0.21	3.14±0.13	1.55 (-1.45 to 4.56)	0.22 (-0.62 to 0.77)		
505 CoD (s)	RBRT	2.50±0.14	2.35±0.12	-5.67 (-8.12 to -3.22) †	-1.12 (-1.79 to -0.45)	-0.29±0.04 †	-2.16 (-2.99 to -1.34) ^{B}
	CG	2.41±0.12	2.55±0.12	5.84 (4.59 to 7.08) †	1.17 (-0.30 to 1.20)		
CMJ (cm)	RBRT	31.0±3.47	35.4±3.78	14.5 (9.65 to 12.1) †	1.19 (0.52 to 1.86)	4.27±0.82 †	1.10 (0.40 to 1.81) ^{B}
	CG	32.7±4.32	32.2±4.51	0.25 (-2.85 to 3.35)	0.01 (-0.69 to 0.70)		
SLJ (cm)	RBRT	191.1±12.08	208.9±15.3	9.38 (6.66 to 12.1) †	1.29 (0.61 to 1.97)	16.1±3.93 †	1.05 (0.35 to 1.75) ^{B}
	CG	203.6±18.61	205.2±20.2	1.02 (2.78 to 4.82)	0.08 (-0.66 to 0.72)		
RSA_{best} (s)	RBRT	7.77±0.22	7.52±0.27	-3.19 (-4.29 to -2.08) †	-1.01 (-1.67 to -0.35)	-0.28±0.05 †	-1.11 (-1.82 to -0.41) ^{B}
	CG	7.19±0.28	7.22±0.26	0.45 (-0.34 to 1.24)	0.11 (-0.65 to 0.73)		
RSA_{total} (s)	RBRT	45.3±1.27	44.0±1.40	-2.76 (-3.75 to -1.77) †	-0.94 (-1.59 to -0.29)	-1.12±0.30 †	-0.77 (-1.45 to 0.09) ^{B}
	CG	44.6±1.65	44.5±1.63	-0.30 (-1.14 to 0.53)	-0.09 (-0.72 to 0.66)		

RBRT = repeated backward running training group; CG = control group; CL = confidence limit; μ = mean; SD = standard deviation; SE = standard error; CoD= change of direction; CMJ=countermovement jump; SLJ= standing long jump; RSA_{best} = repeated sprint ability for fastest time; RSA_{total}= repeated sprint ability of total time; ^{B} = training effect towards RBST; * = $p \leq 0.05$; † = $p \leq 0.001$.