Sprint-Specific Training in Youth: Backward Running vs. Forward Running Training on Speed and Power Measures in Adolescent Male Athletes

Aaron Uthoff,[1] Jon Oliver,[1,2] John Cronin,[1,3] Craig Harrison,[1] and Paul Winwood[1,4]

[1]Sports Performance Research Institute New Zealand (SPRINZ), AUT Millennium, School of Sport and Recreation, AUT University, Auckland, New Zealand; [2]Youth Physical Development Unit, School of Sport, Cardiff Metropolitan University, Cardiff, United Kingdom; [3]School of Health and Medical Science, Edith Cowan University, Perth, Australia; and [4]Department of Sport and Recreation, School of Applied Science, Toi Ohomai Institute of Technology, Tauranga, New Zealand

Abstract

Uthoff, A, Oliver, J, Cronin, J, Harrison, C, and Winwood, P. Sprint-specific training in youth: Backward running vs. forward running training on speed and power measures in adolescent male athletes. *J Strength Cond Res* 34(4): 1113–1122, 2020 —This study compared the effects of 2 sprint-specific training programs against the natural development of speed, power, and stiffness in a group of adolescent male athletes. Forty-three male adolescents (aged 13–15 years) were randomly assigned to 1 of 2 training groups; backward running training (BRT = 26), or forward running training (FRT = 17). A physical education class (n = 24) of similar age constituted a control (CON) group. Both training groups performed running sessions matched for distance and intensity biweekly for 8 weeks. Parametric and magnitude-based inferences were used to analyze within group (pre-post measures) and between group (gain scores) for 10-m, 10- to 20-m, and 20-m sprint times, vertical countermovement jump (CMJ) height, and vertical leg stiffness. Both running groups significantly improved ($p \leq 0.05$) in all performance tests from pre-training to post-training, with effect sizes ranging from −1.25 to 0.63. When the groups were compared, the BRT and FRT groups improved significantly ($p \leq 0.01$) on all sprint performances and stiffness relative to the CON group. The BRT group demonstrated favorable effects for 10-m and 20-m sprint performances (effect size [ES] = −0.47 and −0.26, respectively) and CMJ height (ES = 0.51) compared with the FRT group. These results demonstrate that forward and backward sprint-specific training programs enhance speed and power measures more than natural development in adolescent male athletes. Furthermore, the greater training responses in sprint performance and CMJ ability indicate that BRT is a useful tool for improving concentric strength and power and may be classified as a sprint-specific training method.

Key Words countermovement jump, sprint training, transfer, stiffness

Address correspondence to Aaron Uthoff, uthoffaaron@gmail.com.

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Introduction

Sprint performance over short distances has been identified as a key characteristic of successful young athletes around the time of their adolescent growth spurt (19). Boys commonly experience their adolescent development between 12 and 16 years of age (3). Given the importance of sprint ability in sport and suggestion that speed development can be optimized during adolescence (15), it is no surprise that a myriad of specific and nonspecific training methods have been developed to enhance neural and structural characteristics associated with sprint performance in adolescents (7,18). Sprint-specific training refers to free sprinting (i.e., straight line sprinting with passive recovery), resisted sprinting, or assisted sprinting, whereas nonspecific sprint training corresponds to other methods, such as strength, power, or plyometric training (31,32). An abundance of research is available highlighting the benefits of nonspecific training methods on sprint performance and underlying determinants of speed, such as lower-body power and stiffness (2,16,25); yet, the optimal development of speed and power measures in adolescent male athletes using sprint-specific training methods requires further understanding.

Researchers have reviewed the effectiveness of sprint-specific training on boys' sprinting ability, concluding that free sprinting is a beneficial method for enhancing short-sprint speed up to 20 m with moderate to large effects

(24,31). From these 2 reviews, a total of 6 studies were identified, which measured the effects of straight-line free sprint training on running performance. Although the current reviews provide a comprehensive overview of the available scientific literature, the effects of anecdotal training methods yet to be empirically scrutinized remain unknown. For example, backward running (BR) has been used as part of specific training procedures in a variety of athletic sports (11,37). However, to the authors' knowledge, the effects of BR on forward sprint performance in adolescent athletes are absent from literature.

Like forward running (FR), BR occurs in bursts during many over-ground sports (e.g., soccer, rugby, American football, and most racquet sports) (22). A recent review of BR by Uthoff et al. (37) highlights the immediate and long-term effects of BR on athletic performance. Sports warm-up programs such as the "FIFA 11+," "Harmoknee," and "Prevent Injury and Enhance Performance" include BR to prepare adolescent athletes for the demands of competition, reduce injury rates (28,33), and enhance performance (1,27). The use of BR has been recommended in adult sports training programs because of its ability to improve power output (36) while concomitantly reducing stress on the knee joint (29) compared with FR. Furthermore, it has been theorized that training adaptations from BR may transfer to FR tasks (11,20). Evidence for this effect has been reported in adult populations (34,35). For example, BR training (BRT) has been shown to improve change of direction performance (34,35), increase foot speed in a ladder test (35), and maintain 20-m sprint performance times (35). Although previous findings are promising in adults, it is unknown how these types of training adaptations might transfer to adolescent athletes. Given that BR seems to be a method that promotes injury prevention, increased power output, and performance transfers to FR tasks, the lack of research attempting to quantify the effects of BR on these outcomes in adolescent athletes is surprising.

Most research into the trainability of speed and power in adolescent athletes has explored the effectiveness of non-specific sprint training methods. Methods such as strength training and plyometric training have been shown to enhance speed and lower-body power and force characteristics (2,16). Similarly, sprint-specific training methods are known to improve sprinting performances in adolescents (24,31). Although, relatively few studies are available on the trainability of speed in young athletes using free FR training (FRT) or the effects of this type of training on lower-body power and force measures in pediatric populations. Furthermore, it is unknown whether BRT influences performance outcomes and whether these adaptations transfer to forward sprint ability in adolescent athletes. Therefore, the primary aim of the current research was to explore the effects of free BRT and FRT programs and quantify the potential training-related adaptations these methods promote on sprinting performance and underlying determinants of speed, such as leg stiffness and lower-body power in adolescent male athletes.

Methods

Experimental Approach to the Problem

A cluster randomized control trial was conducted to quantify the effects of 8 weeks of biweekly progressive running training, either forward or backward. To determine the effectiveness of the sprint-specific training programs on speed and power measures, sprinting ability, jumping performance, and vertical leg stiffness were tested before and after training. Boys enrolled in an athletic development program at their school were divided into a BRT group ($n = 26$) and an FRT group ($n = 17$). A control (CON) group ($n = 24$) of the same age and physical characteristics was recruited from the school to assess the effects of natural growth on the selected performance measures. The CON group participated in their school's normal physical education (P.E.) curriculum, but not any structured training program. Habituation sessions for the performance tests occurred in week 1, baseline testing was administered in week 2, supervised training was performed for the following 8 weeks, and finally post-testing was concluded in week 11. Quantitative analyses were conducted to test scores from pre-training to post-training, while qualitative meaning of any observed changes in the independent variables were examined using inferential statistics.

Subjects

A group of 67 adolescent male athletes (aged 13-15 years) from a boys' high-school volunteered to participate in this study. Forty-three subjects were recruited from their school's athlete development program and randomly assigned to either a BRT group ($n = 26$) or an FRT group ($n = 17$). The remaining subjects were recruited from a P.E. class, where they participated in their school's normal P.E. curriculum, serving as a control (CON; $n = 24$) to compare the training effects on the performance measures to those of normal maturation. The athlete development program at the school was an option for students who wished to participate in organized training in place of their normal P.E class. Noninvasive anthropometric measurements were used to calculate maturity offset using an equation developed by Mirwald et al. (21). There were no significant differences between groups for physical characteristics or maturity offset. Table 1 outlines a summary of the subject's characteristics.

Subjects were included in this study if they were males between the ages of 13 and 15 years, enrolled in a public high-school, and free of any medical issues or injuries that may have compromised their participation or performance. Subjects were excluded if they did not meet the above criteria or failed to adhere to the training program with above 80% attendance.

After being informed about the benefits and risks of participating in this research, written consent was provided

TABLE 1. Subject characteristics (mean ± *SD*).*

Parameters	All subjects ($n = 62$)	CON group ($n = 23$)	BRT group ($n = 25$)	FRT group ($n = 14$)
Age (y)	14.61 ± 0.31	14.60 ± 0.31	14.59 ± 0.29	14.63 ± 0.35
Height (cm)	171.95 ± 9.68	170.10 ± 11.84	174.96 ± 8.27	169.96 ± 7.34
Body mass (kg)	62.24 ± 13.08	59.73 ± 13.65	64.84 ± 13.96	61.68 ± 10.66
Peak height velocity (y)	1.08 ± 0.76	1.02 ± 0.09	1.17 ± 0.67	1.05 ± 0.67

*CON = control; BRT = backward running training; FRT = forward running training.

by all parents/guardians and consent was obtained from the boys. All procedures were reviewed and approved by Auckland University of Technology's Research Ethics Committee.

Procedures

Two baseline testing sessions and a post-training testing session were conducted at the same time of day, on the same wooden sprung floor, in the same indoor school gymnasium, using the same testing order for all performance tests. The participants wore the same clothing and footwear for each testing and training session, were asked to avoid any strenuous activity during the 12 hours preceding each session, and maintain their normal dietary intake before and after each session. The subjects participated in 2 orientation sessions, separated by 3 days, to habituate themselves with the equipment, experimental procedures, and movements 2 weeks before the study commenced. The participants' anthropometric measurements (height, seated height, and body mass) were obtained during the first testing session. Thereafter, each participant performed a 15-minute standardized warm-up consisting of skipping, jumping, FR, BR, and sideways running progressively increasing in intensity over 20 m, interspersed with dynamic stretching of the lower limbs. Each testing session was used to determine the participants' 10-m, 10- to 20-m, and 20-m sprint times (s), countermovement jump (CMJ) height (cm), and vertical leg stiffness. Each performance test was completed twice by all participants in every group during each testing session. Five minutes of passive recovery was given between each test. Average performance data for each test were used for analysis. Baseline testing took place twice to establish the reliability of the variables with the examined population before the 8-week study. Coefficient of variation (CV) was computed to determine interday reliability of the 2 pretest performances; 10-m sprint time (CV = 2.83%), 10- to 20-m sprint time (CV = 0.23%), 20-m sprint time (CV = 1.76%), vertical CMJ (CV = 4.24%), and hopping tests (CV = 4.34%).

Speed, Power, and Stiffness Testing. Sprinting performance times over 20 m and splits from 0- to 10-m and 10- to 20-m

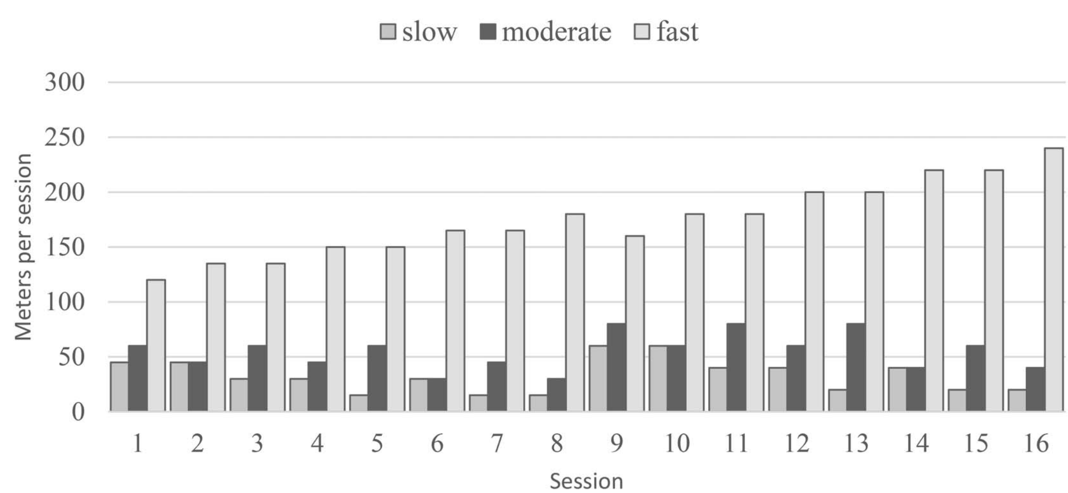

Figure 1. Volume by intensity per session for duration of running program.

Table 2. Eight-week BRT and FRT program.*

	Running intensity	Reps	Distance (m)	Distance per intensity (m)	Total session distance (m)
Week 1					
Session 1	Slow	3	15	45	225
	Moderate	4	15	60	
	Fast	8	15	120	
Session 2	Slow	3	15	45	225
	Moderate	3	15	45	
	Fast	9	15	135	
Week 2					
Session 1	Slow	2	15	30	225
	Moderate	4	15	60	
	Fast	9	15	135	
Session 2	Slow	2	15	30	225
	Moderate	3	15	45	
	Fast	10	15	150	
Week 3					
Session 1	Slow	1	15	15	225
	Moderate	4	15	60	
	Fast	10	15	150	
Session 2	Slow	2	15	30	225
	Moderate	2	15	30	
	Fast	11	15	165	
Week 4					
Session 1	Slow	1	15	15	225
	Moderate	3	15	45	
	Fast	11	15	165	
Session 2	Slow	1	15	15	225
	Moderate	2	15	30	
	Fast	12	15	180	
Week 5					
Session 1	Slow	3	20	60	300
	Moderate	4	20	80	
	Fast	8	20	160	
Session 2	Slow	3	20	60	300
	Moderate	3	20	60	
	Fast	9	20	180	
Week 6					
Session 1	Slow	2	20	40	300
	Moderate	4	20	80	
	Fast	9	20	180	
Session 2	Slow	2	20	40	300
	Moderate	3	20	60	
	Fast	10	20	200	
Week 7					
Session 1	Slow	1	20	20	300
	Moderate	4	20	80	
	Fast	10	20	200	
Session 2	Slow	2	20	40	300
	Moderate	2	20	40	
	Fast	11	20	220	
Week 8					
Session 1	Slow	1	20	20	300
	Moderate	3	20	60	
	Fast	11	20	220	
Session 2	Slow	1	20	20	300
	Moderate	2	20	40	
	Fast	12	20	240	

*BRT = backward running training; FRT = forward running training.

TABLE 3. Technical cues for BR emphasized for the BRT group.*

1. Slight lean of the chest forward
2. Push explosively through the ball of the foot on the ground
3. Use similar arm action to forward running, i.e., contralateral arm/leg action
4. High heel recovery of the swing leg
5. Extend the swing leg behind by kicking and reaching rapidly

*BR = backward running; BRT = backward running training.

were evaluated using SpeedlightV2 wireless dual-beam photocell timing gates (Swift Performance Equipment, Australia). Timing gates were placed 1.5 m apart at the start, 10- and 20-m distances, with photocell heights set at 92.5 cm (top beam) and 68 cm (bottom beam) to correspond with approximately the center of mass of the participants. Participants were instructed to start in a split stance with their lead leg 50 cm behind the first timing gate and toes of the back foot in line with the heel of the front foot. No rocking or false steps were permitted before starting. Sprinting was encouraged to be completed with maximal effort for each trial. Sprint-running performance up to 20 m has shown good test-retest reliability in adolescence athletes (CV = 1.3–2.0%) (8).

Bilateral vertical CMJ height with full arm action was used to assess lower-body power. A Vertec vertical jump tester (Sports Imports, Columbus, OH, USA) was used to quantify jump height. The lowest vane was individually adjusted, so that it corresponded to within 0.5 cm of each participant's maximal standing reach height (26). Participants were requested to use their dominant hand to displace the highest possible vane with an overhead arm swing at the highest point of their jump. Height was determined from the Vertec system as the number of vanes displaced above the original standing reach height to the nearest 1.27 cm. Jump height was then calculated by subtracting the standing reach height from the maximal jump and reach height determined from the highest displaced Vertec vane (10). Between each attempt, all vanes were repositioned, so that multiple trials could be recorded.

Leg stiffness was measured using a field-based submaximal hopping test (17). Participants were asked to hop bilaterally for 20 consecutive hops on a portable contact mat (Fitness Technology, Skye, Australia) at a frequency of 2.5 Hz. Participants were instructed to minimize foot-ground contact time while hopping to an auditory signal produced using an electronic metronome. Ten consecutive hops closest to the designated frequency were used for analysis. Absolute leg stiffness (kilonewtons per meter; $K_N \cdot m^{-1}$) was calculated by modeling the vertical ground reaction force, based on the flight and contact time during hopping (6). The measures of body mass, contact time, and flight time were entered into an equation proposed by Dalleau et al. (6) in equation 1, which has been shown to be a valid and reliable calculation in adolescents (17).

$$\text{Vertical leg stiffness} = \left(\frac{M \times \pi (T_f + T_c)}{T_c^2 \left(\frac{T_f + T_c}{\pi} - \frac{T_c}{4} \right)} \right) \Big/ 1000, \quad (1)$$

where M was the body mass and T_c and T_f were ground contact time and flight time, respectively.

Running Training Program. Running training was conducted twice a week for 8 weeks on nonconsecutive days. The running program was conducted in place of the athletes' normal P.E. curriculum, and in addition to their regular sport training (i.e., typically 2 training sessions and 1 competition game a week). The running training program involved participants performing linear running over a range of intensities either forward or backward. Each training session was conducted after a standardized progressive warm-up resembling the one used during testing. Progressive overload principles were incorporated into the program by increasing the overall intensity of the session through autoregulated running speed and running distance (Figure 1). The intensities of slow, moderate, and fast correspond to approximately 20–45, 50–75, and ≥95% of maximal effort, respectively. These speeds were chosen to reflect common running intensities which young male athletes are capable of self-selecting using autoregulation (38). Table 2 outlines the repetitions by intensity over the prescribed distances for each training session. Equal volume and intensity were prescribed for both the BRT and FRT groups. A duration of 8 weeks was chosen for this study to exemplify how a running training program can be implemented and assessed over a typical school term in a high-school athlete development program.

Because of the novelty of high-speed BR, special attention was focused on correct BR technique by the means of demonstration and verbal feedback in the early sessions. Technical characteristics of BR stressed during training are presented in Table 3. The FRT group also received specific technical instructions, such as; (a) "knee-up and toe-up," (b) "drive your arms from cheek to hip," (c) "strike the ground with the ball of your foot," and (d) "strike the ground under your hips and push back."

Statistical Analyses

The statistical analyses were performed using Microsoft Excel (version 15.28; Microsoft, Seattle, WA, USA) and SPSS 24.0 for MAC OS (SPSS, Inc., Chicago, IL, USA). The data were explored using histogram plots, and the normality of the distribution for all variables was tested using the Kolmogorov-Smirnov test. Homogeneity of variance was tested using the Levene's test. Thereafter, descriptive statistics were calculated and reported as mean values and *SD*s. Within-group differences between pre-training and post-training for all performance variables were analyzed using paired *t*-tests. Within-group percentage change and effect size (ES) were calculated to quantify the magnitude of the performance change in each group's performance tests. Within-group ES was calculated by dividing the difference between the mean performance change (i.e., post-training results − pre-training results) by the pooled SD for each performance variable (5). The smallest worthwhile individual change (SWC = 0.2 × *SD*) was calculated on the pooled *SD* of both pretraining session scores for all groups and converted to a percentage for each performance variable, where changes were deemed small (0.2 × *SD*), moderate (0.6 × *SD*), or large (1.2 × *SD*) (13). Training-related effects between groups were assessed using a 1-way analysis of variance on the change score (mean difference from pre-training to post-training) for each performance variable, similar to Winwood and Buckley (40). Sidak post hoc comparisons were applied if a significant F value was observed to locate pairwise differences. The intervention ES was calculated by dividing the difference between groups' change scores by their pooled SD for each performance variable. Classification of ES was as follows: trivial (<0.20), small (≥0.20 to <0.60), moderate (≥0.60 to <1.2), and large (≥1.2) (5,12). Significance was accepted at the $p \leq 0.05$ level, and 95% confidence intervals were used for all analyses.

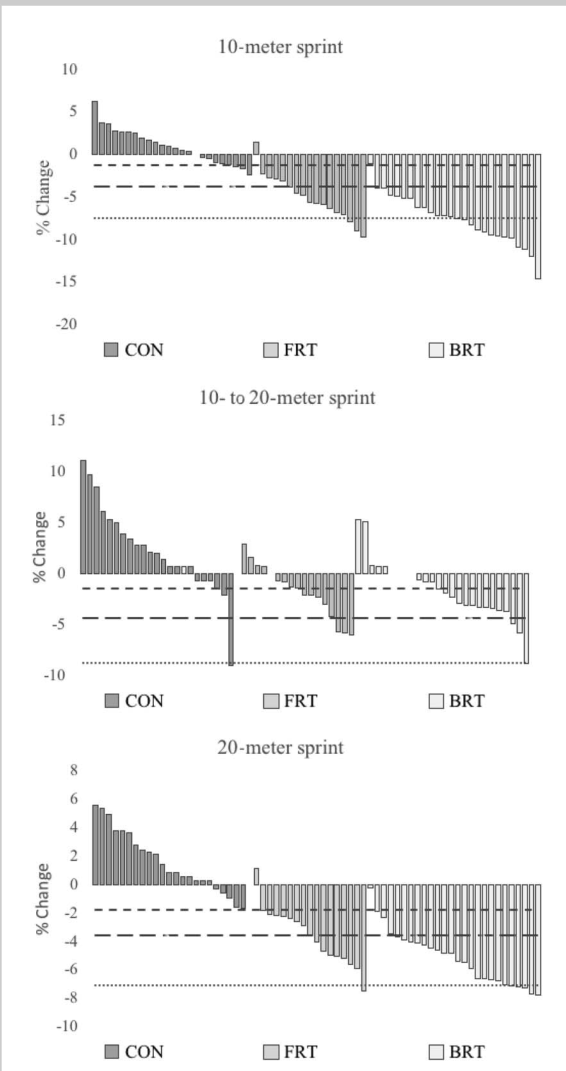

Figure 2. Graphical illustration of individual percentage change for sprinting performances over 10 m, 10–20 m, and 20 m from pre-training to post-training by group. ▬ ▬Small response (SWC = 0.2); ▬▬ ▬ moderate response (MWC = 0.6); ------- large response (LWC = 1.2); FRT = forward running training; BRT = backward running training; CON = control; SWC = smallest worthwhile change. MWC = moderate worthwhile change; LWC = large worthwhile change.

RESULTS

Performance testing data for the BRT, FRT, and CON groups are presented in Table 4, including within-group

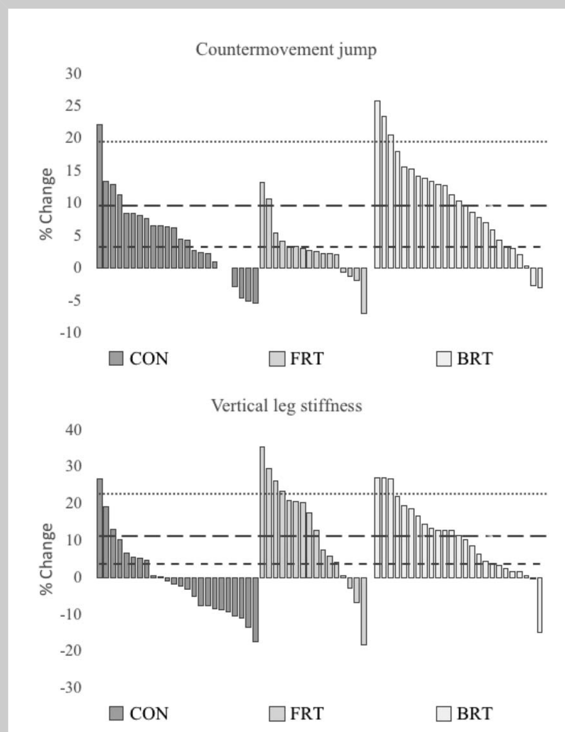

Figure 3. Graphical illustration of individual percentage change for countermovement jump height and vertical leg stiffness performance from pre-training to post-training by group. ▬ ▬Small response (SWC = 0.2); ▬▬ ▬ moderate response (MWC = 0.6); ------- large response (LWC = 1.2); FRT = forward running training; BRT = backward running training; CON = control; SWC = smallest worthwhile change. MWC = moderate worthwhile change; LWC = large worthwhile change.

TABLE 4. Descriptive performance testing results with for CON, FRT, and BRT groups including within-group changes from pre-training to post-training and between-group differences of the mean changes.*†

Performance test	Group	Pre (mean ± *SD*)	Post (mean ± *SD*)	Performance change (%) (95% CI)	Pre-post training effect size (ES)	Diff FRT-CON (mean ± *SE*)	Effect size	Diff BRT-CON (mean ± *SE*)	Effect size	Diff BRT-FRT (mean ± *SE*)	Effect size
10-m sprint (s)	CON	1.97 ± 0.11	1.99 ± 0.11‡	1.10 (0.31 to 1.89)	0.20	−0.12 ± 0.02‖	-1.29^{F}	−0.17 ± 0.02‖	-1.37^{B}	−0.06 ± 0.02§	-0.54^{B}
	FRT	1.94 ± 0.07	1.84 ± 0.09‖	−5.03 (−6.34 to −3.71)	−1.25						
	BRT	1.97 ± 0.11	1.82 ± 0.08‖	−7.66 (−8.79 to −6.53)	−1.20						
10- to 20-m sprint (s)	CON	1.43 ± 0.07	1.46 ± 0.09‡	2.29 (0.54 to 4.04)	0.41	−0.06 ± 0.08§	-0.45^{F}	−0.05 ± 0.02‖	-1.05^{B}	0.00 ± 0.01	0.04
	FRT	1.40 ± 0.09	1.37 ± 0.08§	−1.71 (−2.95 to −0.47)	−0.29						
	BRT	1.40 ± 0.13	1.38 ± 0.11§	−1.43 (−2.63 to −0.23)	−0.24						
20-m sprint (s)	CON	3.38 ± 0.15	3.43 ± 0.16§	1.62 (0.74 to 2.50)	0.36	0.18 ± 0.03‖	-1.20^{F}	−0.22 ± 0.02‖	-1.38^{B}	−0.05 ± 0.02**	-0.29^{B}
	FRT	3.43 ± 0.15	3.22 ± 0.16‖	−3.66 (−4.63 to −2.70)	−0.79						
	BRT	3.37 ± 0.25	3.20 ± 0.21‖	−5.07 (−5.78 to −4.24)	−1.04						
CMJ (cm)	CON	45.19 ± 6.94	47.27 ± 7.18§	4.93 (2.35 to 7.52)	0.30	−0.66 ± 0.79	−0.10	4.57 ± 1.73‖	0.63^{B}	5.23 ± 1.75‖	0.76^{B}
	FRT	54.08 ± 5.79	55.50 ± 5.48‡	2.82 (0.54 to 5.11)	0.25						
	BRT	53.29 ± 8.20	58.50 ± 8.41‖	9.88 (7.25 to 13.18)	0.83						
Stiffness ($kN \cdot m^{-1}$)	CON	30.74 ± 5.76	30.38 ± 5.92	−0.56 (−4.80 to 3.69)	−0.07	−3.64 ± 1.40§	0.67^{F}	−3.83 ± 0.90‖	0.65^{B}	−0.19 ± 1.66	−0.03
	FRT	29.73 ± 4.82	33.01 ± 4.37§	12.37 (5.23 to 19.51)	0.71						
	BRT	33.89 ± 6.00	37.36 ± 6.72	10.59 (6.67 to 14.50)	0.54						

*CI = confidence interval; CON = control; FRT = forward running training; BRT = backward running training; CMJ = countermovement jump.
†C Effect toward CON; F Training effect toward FRT; and B Training effect toward BRT.
‡Significant ($p \leq 0.05$) for within-group and between-group performances.
§Significant ($p \leq 0.01$) for within-group and between-group performances.
‖Significant ($p \leq 0.001$) for within-group and between-group performances.

changes from pre-training to post-training and between-group differences of the mean changes. The within-group analysis revealed that BRT elicited significant changes ($p \leq 0.01$) in sprint times, CMJ height, and leg stiffness with improvements ranging from small to large from pre-training to post-testing. Significant differences ($p \leq 0.05$) were reported after FRT for sprint times, CMJ performance, and leg stiffness, with beneficial effects ranging from small to large. The CON group reported mixed significant results, evident by small detrimental effects on sprinting performance ($p \leq 0.05$) over all distances and small beneficial effects on CMJ height ($p \leq 0.05$).

The BRT group had the highest relative number of individual responses above the SWC for 10 m-times (96%), 20-m times (96%), CMJ height (80%), and vertical leg stiffness (72%). The FRT group demonstrated the greatest relative number of responses above the SWC for 10- to 20-m times (56%). Performance gains in CMJ height were experienced in 58% of the CON group. Moderate to large gains were experienced in 96% of the BRT group for 10-m and 20-m performance and 53%–65% of the FRT group, respectively. More than half of the BRT (52%) and FRT (50%) groups experienced moderate to large gains in leg stiffness while just over a quarter were over the SWC threshold in the CON group (27%). Note that the SWC for sprinting performance is negative to reflect that decreases in sprint times are associated with improvements in performance. Figures 2 and 3 provide graphical references illustrating the individual percentage changes relative to the SWC detected for the BRT, FRT, and CON groups for sprinting performances and lower-body power and stiffness measures, respectively.

When the mean change scores between the groups were compared, statistically significant main effects were reported for all performance tests ($p \leq 0.001$). Compared with the CON group, significant differences ($p \leq 0.001$) were reported to be favorable for BRT on all performance tests, where large changes occurred for sprint times, and moderate changes were seen in CMJ height and vertical leg stiffness, respectively. The FRT group displayed significant improvements ($p \leq 0.01$) compared with the CON group in sprinting ability and vertical leg stiffness, where small to large effects were present for each performance test, respectively. Comparisons between training groups reported significant differences ($p \leq 0.05$) with small to moderate effects for 10-m and 20-m sprint times and CMJ height in favor of BRT over FRT.

Discussion

The purpose of this research was to understand the effects of BRT and FRT programs on speed and power measures in adolescent male athletes. This study is the first to investigate the effects of performing free BRT or FRT on short-sprint speed and power measures in adolescent athletes. The major finding of this study was that individuals in both running groups improved sprinting performance and vertical leg stiffness compared with the individuals in the CON group who participated in normal P.E. curriculum. Moreover, BRT seemed to provide the greatest performance benefits for CMJ height and 10-m and 20-m sprint times compared with the CON and FRT groups.

Findings from this study revealed training-related improvements in short sprinting performance up to 20 m for both FRT and BRT groups compared with the CON group. This is in agreement with previous reports that free sprint training enhances sprint performances up to 20 m more than natural development in adolescent male athletes (23). In addition, the current research found that BRT provided greater gains in sprinting performance over 10 and 20 m compared with FRT. This finding is in line with a previous study, which concluded that BRT was more effective at maintaining FR sprint ability than FRT in a group of 17 trained netball players (35). This is the first study to demonstrate that BR can be used as a training method to significantly enhance FR sprint performance. An explanation for this finding could be that both directions of locomotion are generated by the same basic neural mechanisms (9,14,20). Neurological adaptations are known to occur in response to periods of sprint training (30). By training 1 direction of running, neurological adaptations may result for both BR and FR (11,20). Therefore, BR may be classified as a sprint-specific training method.

A higher number of participants in the BRT and FRT groups experienced adaptations greater than the SWC compared with the CON group, with all but 1 participant in the BRT group experiencing moderate to large gains in 10-m time. Although improvements in 10- and 20-m sprint performance were reported after both the BRT and FRT programs, it is important to distinguish that gains in 20-m performance were primarily a result of increased speed over the first 10 m. This is especially true for the BRT group, who increased performance more over 10 m than 20 m compared with the CON and FRT groups. Although, this study demonstrated that improvements in 10-m sprint performance have subsequent benefits over longer distances up to 20 m. It seems that sprint-specific training, either forward or backward, increases early acceleration over 10 m to a greater extent than late acceleration, or performance over 20 m, based on the relatively larger effects identified from pre-training to post-training. As BR is known to be achieved through higher step frequencies and lower step lengths compared with FR (37), increases in sprinting performance may be a result of alterations in step kinematics, which are representative of early accelerative sprinting (39), i.e., 0–10 m. However, further research using floor-level optical timing systems or video are required to substantiate this posit.

The current study revealed that BRT yielded moderate effects for CMJ performance (↑9.9%), whereas FRT had trivial effects on jumping ability (↑2.8%). Moreover, more than half of the BRT group demonstrated a moderate to large worthwhile change in CMJ height. The larger increase in CMJ height displayed in the BRT compared with FRT group in this study contradicts a previous report by Terblanche and Venter (35), which found female netball athletes aged 19–20 years improved CMJ performance more after FRT (↑2.6%) compared with sport-specific BRT (↑0.25%). Differences between this study and those of Terblanche and Venter (35) could be related to either the technical running model used or the amount of work performed during training. Terblanche and Venter (35) applied maximal effort BR in a sport-specific program, mimicking FR drills, with limited mention of BR technique, distance, or speed. This study, in contrast, used principles of overload to progress BR up to maximal intensity, as a specific training drill where biomechanical components were emphasized through a combination of demonstration and verbal feedback. Therefore, the effect of BRT may be influenced by the quality and attention to direction-specific running mechanics. Ultimately, training BR seems to have favorable transfer to FR and movements related to lower-body power, i.e., CMJ height.

The significant improvement in vertical leg stiffness after BRT (↑10.6%) and FRT (↑12.4%) observed in the current study demonstrates the ability of free sprint-specific training methods to enhance stretch-shortening cycle function in adolescent male athletes. These results are comparable with previous reports that leg stiffness in pediatric populations is enhanced by up to 8% after nonspecific sprint training (i.e., plyometrics) (16). This is important considering increased leg stiffness has been associated with higher maximal sprinting speeds in adolescents (4). This study demonstrated that both running programs were equally effective at inducing performance gains in stiffness when compared with the CON group. This finding is promising because it provides evidence that BR and FR increase vertical leg stiffness more than a traditional P.E. curriculum in adolescent athletes. Given the relationship between stiffness and maximal velocity sprinting, it can be postulated that either direction of sprint-specific training may be used to increase the maximal sprinting speed in young athletes.

Readers should be cognizant that the participants were performing a variety of sport trainings outside of school, which were not quantified and may have had some influence on the training adaptations observed in this study. Nevertheless, this study demonstrates that BR and FR training can be implemented twice a week in a high-school athlete development program intended to improve physical performance in adolescent male athletes. The training gains from BR for sprint performance, leg stiffness, and CMJ ability were comparable with, or greater than, FR. These findings suggest that BR is similarly beneficial to other modes of sprint training for improving sprinting and lower-body performance measures and may be classified as a sprint-specific training method. However, future research should consider using dual energy X-ray absorptiometry scanning to determine body composition changes and help give more insight into the nature of adaptations that take place over periods of BRT. Although this study is limited to male athletes' mid-peak height velocity, it provides a snapshot of sex- and maturity-specific adaptations from sprint-specific training programs compared with a traditional P.E. curriculum in adolescent boys. Such findings are important considering the lack of published data related to the effects of BR and specific FR sprint training in boys. With the recent upsurge in scientific attention aimed at optimizing sprint speed in young athletes, additional training studies are necessary to understand the mechanisms responsible for adaptations related to free and resisted BR and FR in pediatric populations.

Practical Applications

Progressive high-speed BR is recommended as a safe and effective training method for improving athletic performance in adolescent male athletes following sufficient practice and instruction. Speed and strength coaches aiming to optimize the athletic potential of adolescent athletes should consider the following points when implementing sprint-specific training into the training program of their athletes:

- Training adaptations from BR transfer to FR sprint ability and underlying determinants related to fast FR speeds in midadolescent boys.
- Both BRT and FRT can be used to improve sprinting performance, jumping height, and leg stiffness in adolescent athletes.
- Implementing BR into a training program provides a novel stimulus that seems particularly beneficial for improving performance tasks heavily reliant on concentric strength and power.
- Regardless of running direction, coaches should pay particular attention to the technical demands of running movements and be cognizant that effort and intensity may moderate training responses to sprint-specific training methods.

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References

1. Ayala, F, Pomares-Moguera, C, Robles-Palazón, FJ, Del Pilar Garcia-Vaquero, M, Ruiz-Pérez, I, Hernández-Sánchez, S, et al. Training effects of the FIFA 11+ and Harmoknee on several neuromuscular parameters of physical performance measures. *Int J Sports Med* 38: 278–289, 2017.
2. Behm, DG, Young, W, Whitten, JHD, Reid, JC, Quigley, PJ, Low, J, et al. Effectiveness of traditional strength vs. power training on muscle strength, power and speed with youth: A systematic review and meta-analysis. *Front Physiol* 8: 423, 2017.

3. Beunen, GP and Malina, RM. Growth and biological maturation: Relevance to athletic performance. In: *The Child and Adolescent Athlete*. O Bar-Or, ed. Oxford, United Kingdom: Blackwell Publishing, 2005, pp. 3–17.
4. Chelly, MS and Denis, C. Leg power and hopping stiffness: Relationship with sprint running performance. *Med Sci Sports Exerc* 33: 326–333, 2001.
5. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*. New York, NY: Routledge Academic, 1988.
6. Dalleau, G, Bell, A, Viale, F, Lacour, JR, and Bourdin, M. A simple method for field measurements of leg stiffness in hopping. *Int J Sports Med* 25: 170–176, 2004.
7. Faigenbaum, AD, Lloyd, RS, MacDonald, J, and Myer, GD. *Citius, Altius, Fortius*: Beneficial effects of resistance training for young athletes: Narrative review. *Br J Sports Med* 50: 3–7, 2016.
8. Gabbett, TJ. Physiological characteristics of junior and senior rugby league players. *Br J Sports Med* 36: 334–339, 2002.
9. Grasso, R, Bianci, L, and Lacquaniti, F. Motor patterns for human gait: Backward versus forward locomotion. *J Neurophysiol* 80: 1868–1885, 1998.
10. Harman, E and Garhammer, J. Administration, scoring and interpretation of selected tests. In: *Essentials of Strength Training and Conditioning*. TR Breachle and RW Earle, eds. Champaign, IL: Human Kinetics, 2008, pp. 250–292.
11. Hoogkamer, W, Meyns, P, and Duysens, J. Steps forward in understanding backward gait: From basic circuits to rehabilitation. *Exerc Sports Sci Rev* 42: 23–29, 2014.
12. Hopkins, WG. A scale of magnitudes for effect statistics. Available at: http://sportsci.org/resource/stats/effectgam.html. Accessed September 18, 2017.
13. Hopkins, WG. Linear models and effect magnitudes for research, clinical and practical applications. *Sportscience* 14: 49–58, 2010.
14. Ivanenko, YP, Cappellini, G, Poppele, RE, and Lacquaniti, F. Spatiotemporal organization of alpha-motoneuron activity in the human spinal cord during different gaits and gait transitions. *Eur J Neursci* 27: 3351–3368, 2008.
15. Lloyd, RS and Oliver, JL. The youth physical development model: A new approach to long-term athletic development. *Strength Cond J* 34: 61–72, 2012.
16. Lloyd, RS, Oliver, JL, Hughes, MG, and Williams, AC. The effects of 4-weeks of plyometric training on reactive strength index and leg stiffness in male youths. *J Strength Cond Res* 26: 2812–2819, 2012.
17. Lloyd, RS, Oliver, JL, Hughes, MG, and Williams, CA. Reliability and validity of field-based measures of leg stiffness and reactive strength index in youths. *J Sports Sci* 27: 1565–1573, 2009.
18. Lloyd, RS, Radnor, JM, De Ste Croix, MB, Cronin, JB, and Oliver, JL. Changes in sprint and jump performance following traditional, plyometric and combined resistance training in male youth pre- and post-peak height velocity. *J Strength Cond Res* 30: 1239–1247, 2016.
19. Lubans, DR, Organ, PJ, Cliff, DP, Barnett, LM, and Okely, AD. Fundamental movement skill in children and adolescents: Review of associated health benefits. *Sports Med* 40: 1019–1035, 2010.
20. Mehdizadeh, S, Arshi, AR, and Davids, K. Quantifying coordination and coordination variability in backward versus forward running: Implications for control of motion. *Gait Posture* 42: 172–177, 2015.
21. Mirwald, RL, Baxter-Jones, ADG, Bailey, DA, and Beunene, GP. An assessment of maturity from anthropometric measures. *Med Sci Sports Exerc* 34: 689–694, 2002.
22. Mohr, M, Krustrup, P, and Bangsbo, J. Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci* 21: 519–528, 2003.
23. Moran, J, Parry, DA, LIeuan, L, Collison, J, and Rumpf, MC. Maturation-related adaptations in running speed in response to sprint training in youth soccer players. *J Sci Med Sport* 21:538–542, 2017.
24. Moran, J, Sandercock, G, Rumpf, MC, and Parry, DA. Variation in responses to sprint training in male youth athletes: A meta-analysis. *Int J Sports Med* 38: 1–11, 2017.
25. Moran, JJ, Sandercock, GR, Ramirez-Campillo, R, Meylan, CM, Collison, JA, and Parry, DA. Age-related variation in male youth athletes' countermovement jump after plyometric training: A meta-analysis of controlled trials. *J Strength Cond Res* 31: 552–565, 2017.
26. Muehlbauer, T, Pabst, J, Granacher, U, and Büsch, D. Validity of the jump-and-reach test in subelite adolescent handball players. *J Strength Cond Res* 31: 1282–1289, 2017.
27. Neto, MG, Conceição, CS, de Lima Brasileiro, AJA, de Sousa, CS, Carvalho, VO, and de Jesus, LA. Effects of the FIFA 11 training program on injury prevention and performance in football players: A systematic review and meta-analysis. *Clin Rehabil* 31: 651–659, 2017.
28. Olsen, OE, Myklebust, G, Engebretsen, L, Holme, I, and Bahr, R. Exercises to prevent lower limb injuries in youth sports: Cluster randomised controlled trial. *BMJ* 330: 449–452, 2005.
29. Roos, PE, Barton, N, and van Deursen, RWM. Patellofemoral joint compression forces in backward and forward running. *J Biomech* 45: 1656–1660, 2012.
30. Ross, A, Leveritt, M, and Riek, S. Neural influences on sprint training: Training adaptations and acute responses. *Sports Med* 31: 409–425, 2001.
31. Rumpf, MC, Cronin, JB, Pinder, SD, Oliver, J, and Hughes, M. Effect of different training methods on running sprint times in male youth. *Ped Exerc Sci* 24: 170–186, 2012.
32. Rumpf, MC, Lockie, RG, Cronin, JB, and Jalilvand, F. The effect of different sprint training methods on sprint performance over various distances: A brief review. *J Strength Cond Res* 30: 1767–1785, 2016.
33. Soligard, T, Myklebust, G, Steffen, K, Holme, I, Silvers, H, Bizzini, M, et al. Comprehensive warm-up program to prevent injuries in young female footballers: Cluster randomised controlled trial. *Br Med J* 337: a2469, 2008.
34. Swati, K, Ashima, C, and Saurabh, S. Efficacy of backward training on agility and quadriceps strength. *Elixir Hum Physiol* 53: 11918–11921, 2012.
35. Terblanche, E and Venter, RE. The effect of backward training on the speed, agility and power of netball players. *South Afr J Res Sport, Phys Edu Recreat* 31: 135–145, 2009.
36. Threlkeld, AJ, Horn, TS, Wojtowicz, G, Rooney, JG, and Shapiro, R. Kinematics, ground reaction force, and muscle balance produced by backward running. *J Orthopaedic Sports Phys Ther* 11: 56–63, 1989.
37. Uthoff, A, Oliver, J, Cronin, J, Harrison, C, and Winwood, P. A new direction to athletic performance: Understanding the acute and longitudinal responses to backward running. *Sports Med* 48: 1083–1096, 2018.
38. Uthoff, A, Oliver, J, Cronin, J, Winwood, P, and Harrison, C. Prescribing target running intensities for high-school athletes: Can forward and backward running performance be autoregulated? *Sports* 6: 77, 2018.
39. Wild, J, Bezodis, N, Blagrove, R, and Bezodis, I. A biomechanical comparison of accelerative and maximum velocity sprinting: Specific strength training considerations. *Prof Strength Cond* 21: 23–37, 2011.
40. Winwood, PW and Buckley, JJ. Short term effects of resistance training modalities on performance measures in male adolescents. *J Strength Cond Res* 33: 641–650, 2019.