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Effects of a Plyometrics Intervention Program on Sprint Performance

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ABSTRACT

To determine the effects of a sprint-specific plyometrics program on sprint performance, an 8-week training study consisting of 15 training sessions was conducted. Twenty-six male subjects completed the training. A plyometrics group ($N = 10$) performed sprint-specific plyometric exercises, while a sprint group ($N = 7$) performed sprints. A control group ($N = 9$) was included. Subjects performed sprints over 10- and 40-m distances before (Pre) and after (Post) training. For the plyometrics group, significant decreases in times occurred over the 0–10-m (Pre 1.96 ± 0.10 seconds, Post 1.91 ± 0.08 seconds, $p = 0.001$) and 0–40-m (Pre = 5.63 ± 0.18 seconds, Post = 5.53 ± 0.20 seconds, $p = 0.001$) distances, but the improvements in the sprint group were not significant over either the 0–10-m (Pre 1.95 ± 0.06 seconds, Post 1.93 ± 0.05 seconds) or 0–40-m distance (Pre 5.62 ± 0.14 seconds, Post 5.55 ± 0.10 seconds). The magnitude of the improvements in the plyometrics group was, however, not significantly different from the sprint group. The control group showed no changes in sprint times. There were no significant changes in stride length or frequency, but ground contact time decreased at 37 m by 4.4% in the plyometrics group only. It is concluded that a sprint-specific plyometrics program can improve 40-m sprint performance to the same extent as standard sprint training, possibly by shortening ground contact time.

Key Words: sprinting, stretch-shortening cycle, training

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Introduction

Sprint running contributes in varying degrees to successful performance in many sports. A variety of training regimes are commonly used to improve sprinting performance, including sprint drills, overspeed training, sprinting against resistance, weight training, and plyometrics. While plyometric exercise has been used for many years, there is little evidence that this form of training improves sprint performance.

Plyometrics is a type of training that develops the ability of muscles to produce force at high speeds (produce power) in dynamic movements; these movements involve a stretch of the muscle immediately followed by an explosive contraction of the muscle. This pattern of muscle contraction is known as the stretch-shorten cycle (SSC) (12). Plyometric exercises include vertical jumps, during which the athlete jumps as high as possible ''on the spot,'' and bounds, during which the athlete leaps as high and as far as possible, thus moving the body in the horizontal and vertical planes. It is generally accepted that the more specific a training exercise to a competitive movement, the greater the transfer of the training effect to performance (6, 13). Athletes such as sprinters, who require power for moving in the horizontal plane, engage in bounding plyometric exercises, whereas athletes such as high jumpers and volleyball players, who require power to be exerted in the vertical direction, train using vertical jumping exercises (4, 15). Although athletes and coaches involved in sprint training continue to use plyometric exercises (6, 11), there are few data describing the transfer of the training effects from plyometric training in the horizontal plane to sprint performance in the acceleration phases of a sprint.

The findings from the small number of studies in the literature regarding the effects of plyometrics on sprinting are not consistent. Results showing no improvements in sprint times as a result of a plyometrics intervention program have been reported (7, 8, 16). The plyometric exercises employed in these studies were not specific to sprinting, however, and the lack of specificity of the exercises to sprinting may have been responsible for the absence of improvements in sprint times. On the other hand, improvements in 10- and 100-m sprint times have been found after a training intervention that incorporated some sprint-specific plyometric exercises (6). It is unclear, however, whether the reported improvement in sprinting from this study was a result of the sprint training, the plyometrics, or a combination of both training types. Additionally, no data were provided regarding the changes in stride length, stride frequency, or ground contact time, which may have accounted for the changes in sprint performance. Thus, there is a lack of evidence for the effects of a sprint-specific plyometric intervention program on sprint performance. Accordingly, the purpose of the present investigation was to determine the effect of a sprint-specific plyometric intervention program compared with a sprint-training intervention program on sprint performance. It was hypothesized that plyometric training would improve acceleration over the first 20 m of a 40-m sprint to a greater extent than standard sprint training, due to a specificity of training response, because ground contact times during sprinting and plyometrics would be most similar during the early acceleration phase, but ground reaction forces would be higher in plyometrics versus sprinting.

Methods

Subjects

Thirty-two healthy males (mean ± *SD*: age 24 ± 4 years; height, 1.77 ± 0.06 m; and weight, 83 ± 10 kg) with no recent history of plyometric training gave their written informed consent to participate in this study. Ethical approval had first been obtained from the University's ethics committee. Of the 32 subjects selected, 6 failed to complete the training program or testing procedures because of injuries sustained as a result of participation in other activities. The 26 remaining subjects were either rugby ($n = 22$) or touch rugby players ($n = 4$) who played at either the under-21 ($n = 5$) or senior ($n = 21$) levels. The rugby players played in back line or loose forward positions. Subjects performed preliminary 40-m sprints and only those who achieved times of less than 6 seconds were permitted to participate in this investigation. This sprint time was selected to ensure subjects were at least ''average'' sprinters.

Experimental Design

Subjects were randomly allocated to the plyometrics, sprint, or control group and the number of subjects in each of these groups at the conclusion of the study was 10, 9, and 7 respectively. Subjects in the plyometrics and sprint groups took part in 2 training sessions per week during all weeks in the intervention apart from week 4, during which only 1 session was conducted because of the unavailability of most subjects during this week. Testing procedures were conducted on 2 occasions prior to commencing training, and on 2 occasions following the conclusion of the intervention. The first of the pretraining testing sessions was a familiarization session in which subjects performed the warm-up procedures and sprint tests as detailed below. At the second testing session, pretraining data were collected. The pretraining testing session, the familiarization session, and the commencement of training were separated by 3 days to ensure full recovery. Subjects participated in the testing procedures on 2 occasions within a 2-week period following the final training session. The results used in the analysis were those from the day in which the fastest average times were recorded. At least 2 days separated the last training day and the first of the posttesting sessions, and at least 2 days separated the 2 posttraining testing sessions.

Warm-Up

All subjects performed a standardized warm-up prior to performing the sprint tests. Subjects jogged for a 10-minute period at a ''moderate'' pace. Subjects then performed stretches with which they were familiar for approximately 5 minutes. The warm-up was concluded by the performance of 2 40-m submaximal runs (approximately 80% of maximum perceived sprint speed) along the running track.

Sprint Tests

Subjects performed 3–6 maximal effort sprints over distances of 10 and 40 m. The sprints were performed on a hard even surface in an indoor facility. The exact number of sprints performed by each subject depended on whether a force platform, positioned at the 7-m mark of the 10-m sprint and the 37-m mark of the 40-m sprint, was contacted with the entire sole of a foot. The times for the first 3 sprints were used in the analysis. The remaining trials were performed to ensure a minimum of 2 trials had associated force data.

The sprints were separated by a 3–4-minute period to ensure full recovery between sprints. Subjects commenced each sprint from a 3-point stance position in which they positioned the front of either the right or left foot on a line 30 cm behind the start line and touched the same line with either the left hand, if the right foot was the lead foot, or the right hand, if the left foot was the lead foot. The opposite arm was held off the floor. Subjects were instructed to sprint as fast as possible over each distance.

Data Collection Procedures

Sprint Times. Sprint times were recorded (to an accuracy of 0.01 second) by a digital timer (University of Otago, Dunedin, New Zealand) that was connected to opto-reflective switches at the finish line of the 10-m sprint to provide a measure of the changes in performance occurring in the initial acceleration phase. Times were also recorded at the 10-, 20-, 30-, and 40-m marks of the 40-m sprint so that the changes in sprint performance over the continued acceleration phase could be determined.

Biomechanical Data. A high-speed video camera (NAC Inc., Model 200 V-14b, Tokyo, Japan) was used to obtain a video record of the subjects performing the sprints. Strips of tape were fixed to the track at 20-cm intervals within 2 m on either side of the finish line. Each of the trials performed was replayed in slow motion so that the number of strides taken could be counted and the distance from the finish line to the

Table 1. Plyometrics and sprint training programs.

Week	Plyometrics program: Exercise	Sets	Reps	Sprint program: Sprint distance (m)	Reps
1	Double-leg tuck jump	5	8	40	5
	Double-leg speed jump	5	8	40	5
2	Double-leg tuck jump	5	8	40	5
	Single-leg tuck jump	2	5	25	2
	Double-leg speed jump	5	8	40	5
3	Double-leg bound	2	6	50	2
	Single-leg tuck jump	2	8	40	2
	Double-leg speed jump	4	10	55	4
	Single-leg hop	4	8	40	4
4	Double-leg bound	4	6	50	4
	Single-leg tuck jump	2	8	40	2
	Single-leg hop	4	8	40	4
	Alternate-leg bound	5	8	40	5
5	Single-leg hop	2	8	40	2
	Single-leg speed hop	2	8	35	2
	Alternate-leg bound	8	8	40	8
	Alternate-leg stairbound	3	8	30	3
6	Single-leg hop	2	8	40	2
	Single-leg speed hop	2	8	35	2
	Alternate-leg bound	7	10	50	7
	Alternate-leg stairbound	3	10	40	3
7	Single-leg hop	2	8	40	2
	Single-leg speed hop	4	8	35	4
	Alternate-leg bound	2	10	50	2
	Sprint bound	5	10	40	5
	Alternate-leg stairbound	3	10	40	3
8	Sprint bound	8	10	40	8
	Single-leg speed hop	4	8	35	4
	Alternate-leg stairbound	4	12	55	4

point of last foot contact was recorded to the nearest 10 cm.

Average stride length over the 10- and 40-m distances was determined by dividing the number of strides taken over the respective distances by the distance from the start line to the mark at which the foot closest to the finish line landed during the respective sprints. Average stride frequency over each sprint was calculated by dividing the number of strides taken by the time required to complete the respective distance.

Contact time of the foot on the ground during the 2 phases of the sprint was measured using a force platform (1.2 m × 0.6 m, AMTI, Model LRG-3–1, Newton, MA) positioned with the front edge at the 7-m mark of the 10-m sprint (initial acceleration phase) and the 37-m mark of the 40-m sprint (maximum speed). The attainment of maximum speed has been reported to occur at approximately the 35-m mark (10). The force platform was connected to a DAS-16 Interface Box (Keithley Metrabite, Taunton, MA) that was in turn connected to an IBM-compatible PC. The data were sampled at a rate of 2,200 Hz and analyzed by custom-designed software (Labview, National Instruments Corporation, Austin, TX). Contact times were recorded to the nearest millisecond and subjects wore the same shoes at each testing session to prevent any effects that variations in footwear may have had on force-time characteristics.

Training Procedures

All subjects were instructed to refrain from participation in any other form of training during the testing and training period that might improve their speed, including resistance training. Subjects in the plyometrics group participated in a program incorporating 8 weeks of sprint-specific plyometric exercises, while subjects in the sprint group performed 8 weeks of maximal effort sprint training (Table 1). The 8-week training duration was chosen because it is well known that both neural and muscular adaptations can occur within this time frame (13). The number of sprints performed was equivalent to the number of sets of plyometric exercises performed by the plyometrics subjects. The distance of each sprint performed by the sprint subjects was determined by the time taken to perform the corresponding exercise set in the plyometrics group. The plyometrics and sprint regimes were equated in terms of the number of plyometric sets and sprints, and the duration of plyometric sets and sprints so that the volumes of both programs were approximately equal. By equating volume, any effect that different training volumes may have had on sprint performance was removed. The researcher supervised each training session. Subjects were instructed to be physically well rested on each training day. Each training session began with a 10-minute running warm-up at a moderate intensity. This warm-up was followed by leg stretching for approximately 5 minutes. Sets were separated by approximately 3-minute recovery periods and the exercises were performed on grass to reduce the impact forces experienced by the body and therefore reduce the likelihood of sustaining impact-related injuries.

Reliability of Test Variables

The reliability of each test variable was determined in pilot work. Each test variable that was collected in the pilot study was subjected to a 2-way analysis of variance (ANOVA) with the designated factors of number of subjects and number of trials. Intraclass correlation coefficients (ICC) were calculated for each dependent variable using the formula:

$$\mathrm{ICC} = (F - 1)/(F + \mathrm{k} - 1)$$

where F = the test statistic for subjects and k = number of trials (1). ICC values for each test variable were calculated using data from the trials of 1 day's testing to determine the reliability of the test variables from trial to trial. Also, day-to-day ICC values were calculated for each variable using (a) the mean values for the 4 trials of a day, and (b) the fastest trial of each day.

Intertrial ICC values ranged from 0.94 to 0.98 for the 0–40-m times and from 0.80 to 0.89 for the 0–10-m times. Between-day ICC values ranged from 0.92 to 0.98 for the 0–10-, 0–30-, and 0–40-m times. The intertrial ICC values for average stride length over the 10- and 40-m distances were 0.85 and 0.98 for these distances, respectively, while the intertrial ICC values for average stride frequency over 10 and 40 m were 0.62 and 0.82 for these distances, respectively. Day-to-day ICC values for stride frequency and the number of strides taken ranged from 0.85 to 0.99.

For the ground contact time variable, intertrial ICC values were 0.76 and 0.85 for the contact times at the 7- and 37-m marks, respectively. The day-to-day ICC value was 0.80 for contact time at the 7-m mark and 0.70 for contact time at the 37-m mark (note: 37-m contact time data were obtained for only 3 subjects on day 1 resulting in low day-to-day and trial-to-trial ICC values for this variable).

Statistical Power

For within-group comparisons, such as improvement in 40-m sprint time, statistical power ($1 - \beta$) exceeded 0.80 for large effect sizes (mean difference/$SD > 0.8$), but was only 0.56 for medium effect sizes (0.5) as defined by Cohen (5). For differences between groups, statistical power was much lower ($1 - \beta = 0.31$ for large effects). The low statistical power for between-group measures needs to be considered when interpreting the results.

Statistical Analysis

Means and standard deviations were determined for all dependent variables. Mean times, stride length, and stride frequency of the first 3 sprints were used for statistical analysis. Force and contact time from all trials during which the foot fully contacted the force platform were used for analysis. For each dependent variable, a 2-way ANOVA (group × trial) with repeated measures on 1 factor (trial) was used to determine whether differences existed across trials or between groups. If a main or interaction effect was detected, paired *t*-tests were performed to determine specific differences. Differences between groups were established by performing independent *t*-tests on the differences between the pre- and posttest values for each dependent variable between each group. These post hoc results were considered significant at an α level of 0.05.

Results

Changes in Sprint Times

Sprint time over 40 m was significantly improved in the plyometrics group, but although this change was significantly different from the changes observed in the control group, there was no difference in the magnitude of this improvement when compared with the nonsignificant improvement in the sprint group (Figure 1). The plyometrics training also caused improvements over the intervals within the 0–40-m distance (Table 2). Split times decreased significantly for both the 0–10-m and 20–30-m intervals ($p = 0.001$ and $p = 0.03$, respectively). The improvement in time that occurred over the first 10 m (0.05 seconds) accounted for half of the improvement that occurred over the entire 0–40-m distance. The changes in times for the 10- and 40-m sprints were significantly greater than the corresponding changes occurring for the control group (p

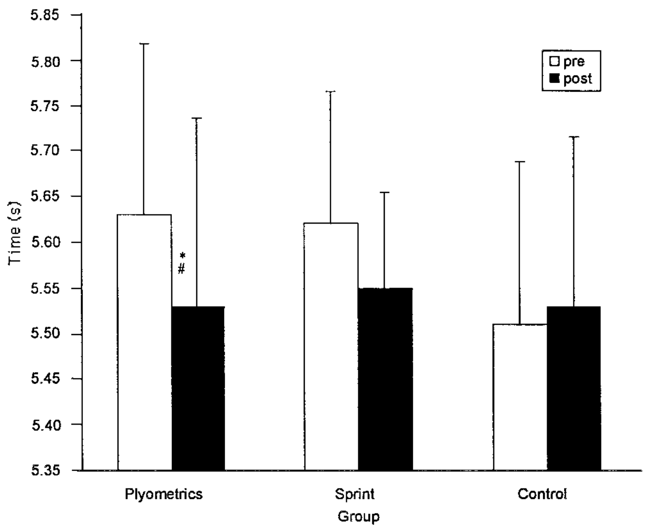

Figure 1. Mean (*SD*) Subject 40-m sprint times before (pre) and after (post) an 8-week intervention for plyometrics ($n = 10$), sprint ($n = 7$), and control ($n = 9$) groups.
* Significant change in time pre to post, $p < 0.01$.
# Change in time for plyometrics group significantly greater than change for control group, $p < 0.05$.

= 0.04 and $p = 0.02$, respectively), but not for the sprint group.

Biomechanical Changes

There were no significant changes in stride length detected over the course of the study for any group. The only change in stride frequency occurred for the sprint group in which stride frequency decreased over the 0–10-m interval ($p = 0.02$) (Table 3).

For the plyometrics group a significant decrease in contact time occurred at the 37-m mark of the 40-m sprint ($p = 0.049$), and this change was significantly greater than the change for the control group ($p = 0.03$). No other changes in contact times were observed in any group over the course of the study (Table 3).

Discussion

The plyometrics intervention appears to have had the greatest effect on sprint performance in the initial acceleration phase. This finding corroborates the results of Delecluse et al. (6), who found that concurrent plyometric and sprint training improved speed over the first 10 m to a greater extent than over the other phases of the sprint. The velocity specificity principle of train-

Table 2. Pre- and posttraining group mean (± *SD*) times (s) over intervals in the acceleration phases of a sprint.

	Plyometrics		Sprint		Control	
Interval	Pre	Post	Pre	Post	Pre	Post
0–10 m	1.96 ± 0.10	1.91 ± 0.08*†	1.95 ± 0.06	1.93 ± 0.05	1.95 ± 0.08	1.95 ± 0.10
10–20 m	1.29 ± 0.03	1.28 ± 0.05	1.29 ± 0.03	1.28 ± 0.02	1.26 ± 0.04	1.25 ± 0.04
20–30 m	1.20 ± 0.04	1.18 ± 0.04‡§	1.20 ± 0.04	1.19 ± 0.03†	1.17 ± 0.03	1.18 ± 0.04
30–40 m	1.17 ± 0.04	1.15 ± 0.04†	1.18 ± 0.04	1.16 ± 0.03	1.14 ± 0.04	1.16 ± 0.04

* Significantly different from pretraining, $p < 0.01$.
† Significantly different improvement from control group, $p < 0.05$.
‡ Significantly different from pretraining, $p < 0.05$.
§ Significantly different improvement from control group, $p < 0.01$.

Table 3. Pre- and posttraining group mean (± *SD*) stride frequency, stride length, and ground contact time.

	Plyometrics		Sprint		Control	
Stride variable	Pre	Post	Pre	Post	Pre	Post
10-m Stride frequency (strides/s)	3.76 ± 0.35	3.74 ± 0.37	4.10 ± 0.27	3.83 ± 0.21*	3.83 ± 0.23	3.77 ± 0.23
40-m Stride frequency (strides/s)	4.06 ± 0.21	4.08 ± 0.24	4.25 ± 0.13	4.23 ± 0.23	4.19 ± 0.23	4.16 ± 0.20
10-m Stride length (m)	1.37 ± 0.12	1.40 ± 0.13	1.29 ± 0.07	1.35 ± 0.05	1.36 ± 0.04	1.36 ± 0.06
40-m Stride length (m)	1.75 ± 0.09	1.78 ± 0.11	1.68 ± 0.07	1.70 ± 0.06	1.73 ± 0.06	1.74 ± 0.04
7-m Contact time (ms)	160 ± 13	153 ± 12	154 ± 15	156 ± 4	154 ± 8	155 ± 8
37-m Contact time (ms)	135 ± 12	129 ± 8*†	128 ± 8	125 ± 5	124 ± 8	125 ± 8

* Significantly different from pretraining, $p < 0.05$.
† Significantly different improvement from control group, $p < 0.05$.

ing may underlie the magnitude of the change in sprint performance occurring in a particular phase of the sprint as a result of a sprint-specific plyometrics program. The greatest gains in strength occur at or near the velocity of muscle action that most closely approximates the velocity of muscle action of training, with the mechanisms underlying this velocity-specific training effect residing in both neural and muscular components (2, 3). In relation to the transfer of plyometrics training to sprinting, it is likely that the greatest improvements in sprinting will occur at the velocity of muscle action that most closely approximates the velocity of muscle action of the plyometric exercises employed in training. An indirect measure of the rate at which forces are produced in the concentric and eccentric actions during sprinting and in plyometric exercises is obtained from contact time data. It is likely that the rates at which forces are produced in the concentric and eccentric actions by the muscles in the plyometric exercises will approximate those in the sprint when the times over which these forces act in the plyometric exercises and the sprints, (i.e., the contact times) are similar. The contact times during the initial acceleration phase of a sprint are similar to the contact times of the exercises employed in this investigation (9, 11, 17). Therefore, the greatest transfer of the plyometrics to sprinting likely occurred during the initial acceleration phase. This theory is supported by Young (17), who suggested that bounding may be considered a specific exercise for the development of acceleration because of the similar contact times of bounding and sprinting during the initial acceleration phase. Further research is required to test the theory that the greatest transfer of sprint-specific plyometrics to sprinting occurs during the phase of the sprint when the contact times of the sprint during that phase are the same as the contact times of the plyometric exercises, because the contact times of the plyometric exercises were not measured in this investigation.

Plyometrics training, with its greater emphasis on power development but lesser specificity, was equally as effective as the sprint training with its greater specificity but lesser potential for power development. Improvements in both groups were, nevertheless, small and this could be due to the influence of inadequate recovery between training intervals on the overall training intensity of each workout. Work-rest ratios were in the order of 1:25, however, which should have provided adequate recovery. The relative effects of training with plyometrics or training with sprints may also depend on the training histories of the athletes. In the present study the subjects were ''competent'' sprinters but unaccustomed to training regularly with sprints. Thus, they had the potential to improve their speed from training with sprints alone. The relative effects of plyometrics training compared with sprint training may be greater for those athletes who have not trained with plyometrics before, but are well accustomed to performing sprints and therefore do not have the same potential for improvements from sprint training alone. Further research that involves a sample of trained sprinters is needed to determine the relative effects of plyometrics versus sprint training on sprint performance. Additionally, the effect on sprint speed of training using concurrent plyometric and sprint training versus plyometric or sprint training alone has not been studied and requires examination.

Changes in stride length and stride frequency during sprinting, occurring as a result of a plyometrics intervention program, have not been reported in the literature and no changes in these variables were detected in the present study. This finding was most likely due to the modest reliability of measurement for the stride variables. Further research is required to determine the changes in stride length and stride frequency that occur as a result of a plyometrics intervention. The finding of a decrease in 37-m contact time confirms the finding of Schmidtbleicher et al. (14) that plyometric training can decrease contact time in dynamic SSC-based activities. These investigators found that contact time in a vertical jump decreased as a result of performing vertical jumps. The magnitudes of the changes in contact times of the vertical jumps employed in the investigation of Schmidtbleicher et al. (14) were similar to the magnitude of the change in contact time at the 37-m mark of the sprint in this investigation. The failure to detect a significant change in contact time at the 7-m mark may be due to the modest reliability of measurement for that variable. Further work is required to determine the mechanisms behind speed improvement as a result of plyometric training.

Practical Applications

The most important finding of this study is that a sprint-specific plyometrics training program can improve sprint performance over distances up to 40 m in length, but this improvement is no greater than improvements observed with standard sprint training. The effects of a sprint-specific plyometrics program appear to be greatest over the initial acceleration period (0–10 m), with more modest performance gains noted over the intervals in the 10–40-m range. The results of this investigation suggest that sports participants who are accustomed to performing sprints over distances up to 40 m could potentially improve sprint speed, particularly in the initial acceleration phase, by adding sprint-specific plyometric exercises to their training. Explosive speed is required in many sports and physical activities; coaches and participants should therefore consider a plyometrics training program that incorporates sprint-specific exercises as part of the overall training plan.

References

1. BARTKO, J.J. The intraclass correlation coefficient as a measure of reliability. *Psychological Rep.* 19:3–11. 1966.
2. BEHM, D.G., AND D.G. SALE. Intended rather than actual movement velocity determines velocity-specific training response. *J. Appl. Physiol.* 74:359–368. 1993a.
3. BEHM, D.G., AND D.G. SALE. Velocity specificity of resistance training. *Sports Med.* 15:374–388. 1993b.
4. CHU, D. *Jumping into Plyometrics.* Champaign, Illinois: Leisure Press, 1992.
5. COHEN, J. . *Statistical Power Analysis for the Behavioural Sciences.* Hillsdale, NJ: Lawrence Erlbaum, 1988.
6. DELECLUSE, C., H. VAN COPPENOLLE, E. WILLEMS, M. VAN LEEMPUTTE, R. DIELS, AND M. GORIS. Influence of high-resistance and high-velocity training on sprint performance. *Med. Sci. Sports Exerc.* 27:1203–1209. 1995.
7. FRY, A.C., W.J. KRAEMER, C.A. WESEMAN, B.P. CONROY, S.E. GORDON, J.R. HOFFMAN, AND C.M. MARESH. The effects of an off-season strength and conditioning program on starters and non-starters in women's intercollegiate volleyball. *J. Appl. Sport Sci. Res.* 5:174–181. 1991.
8. LYTTLE, A.D., G.J. WILSON, AND K.J. OSTROWSKI. Enhancing performance: Maximal power verses combined weights and plyometrics training. *J. Strength Cond. Res.* 10:173–179. 1996.
9. MERO, A. Force-time characteristics and running velocity of male sprinters during the acceleration phase of sprinting. *Res. Q. Exerc. Sport* 59:94–98. 1988.
10. MERO, A., AND P.V. KOMI. Force, EMG-, and elasticity-velocity relationships at submaximal, maximal and supramaximal running speeds in sprinters. *Eur. J. Appl. Physiol.* 55:553–561. 1986.
11. MERO, A., AND P.V. KOMI. EMG, force, and power analysis of sprint-specific strength exercises. *J. Appl. Biomech.* 10:1–13. 1994.
12. NORMAN, R.W., AND P.V. KOMI. Electromyographic delay in skeletal muscle under normal movement conditions. *Acta Physiol. Scand.* 106:241–248. 1979.
13. SALE, D., AND D. MACDOUGALL. Specificity in strength training: A review for the coach and athlete. *Can. J. Appl. Sport Sci.* 6:87–92. 1981.
14. SCHMIDTBLEICHER, D., A. GOLLHOFER, AND U. FRICK. Effects of a stretch-shortening typed training on the performance capability and innervation characteristics of leg extensor muscles. In: *Biomechanics X1-A.* G. de Groot, A. P. Hollander, P. A. Huijing, and G. J. van Ingen Schenau, eds. Amsterdam: Free University Press, 1988. pp. 185–189.
15. WATHEN, D. Literature review: Explosive/plyometric exercises. *Natl. Strength Cond. Assoc. J.* 15:17–19. 1993.
16. WILSON, G.J., R.U. NEWTON, A.J. MURPHY, AND B.J. HUMPHRIES. The optimal training load for the development of dynamic athletic performance. *Med. Sci. Sports Exerc.* 25:1279–1286. 1993.
17. YOUNG, W. Sprint bounding and the sprint bound index. *Natl. Strength Cond. Assoc. J.* 14:18–21. 1992.

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