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ORIGINAL RESEARCH

Speed Improves With Eccentric Hamstring Training in Athletes of Different Maturity Status

Raouf Hammami
University of La Manouba and University of Sfax

Javier Gene-Morales
University of Valencia

Ammar Nebigh
University of La Manouba and University of Sfax

Haithem Rebai
University of Sfax

Juan C. Colado
University of Valencia

Purpose: To investigate the effects of an eccentric hamstring strength training program (EHT) on sprint performance (10-, 20-, and 30-m sprint times) and change of direction speed (4 × 5-m shuttle run and T-Half test) in male European handball athletes at 2 maturity statuses (prepeak and postpeak height velocity [PHV]). ***Methods:*** Forty-five participants (12.68 [1.58] y) were divided into pre-PHV and post-PHV and randomly allocated to a control or intervention group, which performed a guided 2 day per week 6-week EHT of 5 exercises. A mixed-model (within- and between-factor) analysis of variance was conducted. ***Results:*** A significant effect ($P < .05$) of the interaction time × maturity × training was observed in the T-Half, 10, and 30 m tests. Both intervention groups significantly improved in all the tests, except in the 20 m sprint and the post-PHV in the 10 m sprint. Improvements ranged between 0.93% and 5.74% (effect size: 0.07–0.79). Both control groups yielded no improvements in almost all the tests. The improvements of both groups undergoing the intervention (pre-PHV and post-PHV) were not significantly different (only a tendency in the 10 m sprint). ***Conclusion:*** An EHT program combined with European-handball training improve change of direction and sprint performance in pre-PHV and post-PHV male players. Professionals training European handball and similar team-sport athletes should consider including EHT regardless of athlete's maturity.

Keywords: preadolescent, youth, peak height velocity (PHV), change of direction, sprint

Applying an optimal training stimulus within the development of young athletes is crucial for developing adequate movement patterns throughout their maturation and improving their athletic performance. Several resistance training modes are effective in eliciting beneficial training responses in neuromuscular performance in youth; for instance, traditional strength training (27), use of elastic bands (17), plyometrics (18,32), and combined traditional and plyometric training (12,32). Exposure to eccentric muscle actions occurs within the demands of most sports (ie, soccer, European handball, volleyball, basketball) since athletic movements normally include changes of direction (CoDs), deceleration, landing, and hopping (2). In this context, eccentric strength training has been recognized as more effective in improving muscle mass and power, stretch-shortening cycle, sprint, and CoD performance, compared with single mode concentric or combined concentric–eccentric training in young (circa peak height velocity [PHV]) and adult (17–35 y) athletes (3,10,11,16). Researchers commonly use sprint and CoD speed as indicators of neuromuscular fitness in youth (19,23) and within talent identification screens (14).

In light of these facts, Drury et al (11) demonstrated significant improvement in eccentric hamstring strength after a 6-week Nordic hamstring exercise program in young male soccer players of 2 maturity statuses (pre-PHV, less mature and mid-/post-PHV, and more mature). However, this study only examined the efficacy of eccentric training on measures of strength. Other studies focused on performance parameters such as the CoD speed. For instance, a recent review (3) reported improvements with small to large effect sizes (Cohen $d = 0.46$–1.31) in the CoD speed after resistance training programs that emphasized eccentric muscle actions in adult athletic populations. Similarly, 5 cross-sectional studies found significant moderate–large correlations (Pearson $r = .45$–.89) between measures of eccentric muscle strength and CoD speed in adult female (20,33) and male (2,7,36) athletes.

It is also important to bear in mind the potential influence of the maturity status of the athletes on the training effects. Regarding this concern, a previous meta-analysis (35) showed that pre-PHV and circa-PHV boys appeared to benefit most from plyometric training to improve sprint performance, while post-PHV adolescents maximized gains following a combination of strength and plyometric training. Also, Lloyd et al (23) showed that plyometric training might be more

Hammami and Nebigh are with the Higher Institute of Sport and Physical Education of Ksar-Said, University of La Manouba, Tunis, Tunisia. Hammami, Nebigh, and Rebai are with the Research Laboratory: "Education, Motricity, Sports, and Health," University of Sfax, Sfax, Tunisia. Gene-Morales and Colado are with the Research Group in Prevention and Health in Exercise and Sport (PHES), University of Valencia, Valencia, Spain; and the Research Unit in Sport and Health, University of Valencia, Valencia, Spain. Colado is also with the Department of Physical Education and Sports, Faculty of Science of Physical Activity and Sport (FCAFE), University of Valencia, Valencia, Spain. Gene-Morales is also with the Research Institute on Traffic and Road Safety, University of Valencia, Valencia, Spain. Colado (juan.colado@uv.es) is corresponding author.

effective in eliciting short-term gains in jumping and sprinting in pre-PHV boys, whereas post-PHV may further benefit from the additive stimulus of combined training. As can be seen, maturity may play an important role in the trainability of young athletes. However, minimal evidence exists examining an eccentric hamstring training program (EHT) and its potential interaction with the maturity status on performance parameters such as sprint and CoD speed in youth (3).

Therefore, the purpose of the current study was to investigate the effects of a 6-week in-season hamstring eccentric resistance training program on sprint performance (10-, 20-, and 30-m linear sprint times) and CoD speed (4 × 5-m shuttle run and T-Half test), in male athletes at different maturity status (pre-PHV and post-PHV). We hypothesized that pre-PHV players would respond more favorably to eccentric training in sprint performance (16), whereas post-PHV participants would show a greater training response in the CoD/speed (2).

Method

Participants

Forty-five preadolescent and adolescent male European handball players aged between 9 and 14 years (mean = 12.68, SD = 1.58) voluntarily took part in the study. All the participants were members of different teams of the Tunisian Handball Club and had playing experience between 0 (first year playing) and 3 years. All participants were physically active, free from lower-limb musculoskeletal injuries, and participated regularly in European handball team training. None of the participants were involved in any strength and conditioning program outside the team, and their habits were maintained throughout the study. All the participants were below the body mass index 95th percentile of their corresponding age value, which ensured none of them were obese (8,38). Table 1 presents the descriptive characteristics of the sample.

Before starting the study, age at PHV was calculated (see "Design" section), and, depending on whether the PHV value of each participant was positive (under age at PHV) or negative (over age at PHV), they were allocated to the pre-PHV or post-PHV group. The pre-PHV and the post-PHV participants in both the experimental and control groups showed significant differences in almost all the variables ($P < .05$). On the other hand, participants in the experimental and control groups (both pre-PHV and post-PHV) were not statistically different in almost all the variables (Table 1).

Design

This experimental study employed a repeated-measures design to assess the effects of a 6-week (2 d/wk) eccentric strengthening program for the hamstrings in the sprint and CoD performance and evaluate the potential influence of the maturity status (pre-PHV and post-PHV) of the athletes in the outcomes. The duration and frequency of the training program were based on a previously published review that found significant improvements in strength with large to very large effect sizes with EHT programs of 6 weeks and frequency between 1 and 3 days per week (6). The ethics committee of the National Centre of Medicine and Science of Sports of Tunis (CNMSS-LR09SEP01) approved the study, requiring parents to sign an informed consent form. We conducted the study following the Declaration of Helsinki. The staff members provided all athletes and parents with a clear explanation of the study, including the risks and benefits of participation, and informed consent was obtained.

We conducted all the trials and training sessions throughout the second half of the season (April–June 2019). All the participants in the intervention group performed each training session with their respective teams, to maintain their usual training environment. The same certified strength and conditioning coaches supervised all the procedures. The weekly training routine comprised 5 training sessions (approximately 90 min) with a competitive match on weekends. Regular training consisted mainly of tactical skill development (60% of session time) and strength and conditioning routines (40% of session time). Before the commencement of the study and the initiation of testing, players completed a 2-week orientation period (3 sessions/wk) to become familiar with the general environment, form, equipment, and technique of each test (all the athletes) and EHT exercise (only intervention group). We considered athletes familiarized when they could perform multiple repetitions of each exercise with the correct technique. Performance testing occurred before and following the 6-week training period. The testing battery included assessments of sprint performance (times over 10, 20, and 30 m) and CoD speed (4 × 5-m shuttle run and T-Half test).

The staff members randomly allocated participants to either an EHT group (both pre-PHV [n = 10] and post-PHV [n = 12]) or a control group (both pre-PHV [n = 10] and post-PHV [n = 13]). Both groups maintained their standard in-season regimen during the intervention period but only the experimental group performed the eccentric training program. The biological maturity was assessed noninvasively by incorporating measures of chronological age and body height into a regression equation able to predict biological age from PHV (29), to identify the participants as pre-PHV or post-PHV. Previous expert literature has validated the equation for boys, with a SE of the estimate of 0.542 years (29).

Training Program

The 6-week (2 d/wk) EHT intervention consisted of 5 exercises focused on the hamstrings and glutes (Figure 1): the glute hamstring raise, manual glute hamstring rise, single-leg Romanian deadlift, hip thrust, and good morning dumbbell or barbell. The between-session recovery time was 48 hours. Training sets varied between 2 and 3, repetitions between 5 and 8, and intensities between 60% and 80% of one-repetition maximum as can be seen in Table 2. Participants completed a standardized warm-up consisting of low-intensity jogging, CoDs, jumping tasks, and dynamic lower-limb stretching before every session. The staff members instructed participants to keep a straight torso, to control the movement as much as possible through a full eccentric hamstring activation from the start to the end of the repetition, and to return the load using as little effort as possible to minimize loading in the concentric phase. Previous scientific publications report further information on how to control the technique in EHT (2,16,28). Each participant alternated between performing one set and assisting their partner (2). None of the participants dropped out of the study during the intervention period nor reported suffering any adverse effects as a result of the training (neither unrelated to the study) or testing other than symptoms of exercise-induced muscle damage (eg, reduced muscle function or elevated soreness). The compliance rate was above 85% for all the groups, with no significant differences between them.

Data Collection Procedures

First and prior to the beginning of the testing, we enquired about age, and the same researcher measured each player's height and body mass using a height rod (IP0955; Invicta Plastics Limited, Leicester, England) and electronic scale (9179 SV3R; Salter,

Table 1 Descriptive Characteristics of the Sample: Group 1 (n = 10), Group 2 (n = 12), Group 3 (n = 10), and Group 4 (n = 13)

	Intervention		Control			
	Group 1 pre-PHV	Group 2 post-PHV	Group 3 pre-PHV	Group 4 post-PHV	Control intervention comparison (pre-PHV)	Control intervention comparison (post-PHV)
Age, y	11.24 (0.93) (10.70 to 11.79)	14.00 (0.20) (13.89 to 14.11)	11.03 (0.77) (10.67 to 11.57)	13.85 (0.87) (13.42 to 14.32)	$t(18) = 0.56$, $P = 0.58$, $d_{unb} = 0.24$	$t(13.33) = 0.62$, $P = 0.55$, $d_{unb} = 0.23$
Pre–post PHV comparison	$t(9.67) = 9.21$, $P < 0.001$, $d_{unb} = 4.14$		$t(21) = 8.12$, $P < 0.001$, $d_{unb} = 3.29$			
body mass, kg	37.51 (5.23) (34.56 to 40.83)	67.83 (13.86) (60.00 to 75.25)	42.18 (6.10) (38.42 to 45.81)	65.23 (7.41) (61.62 to 69.23)	$t(18) = 1.84$, $P = 0.08$, $d_{unb} = 0.79$	$t(23) = 0.59$, $P = 0.56$, $d_{unb} = 0.23$
Pre–post PHV comparison	$t(14.56) = 7.01$, $P < 0.001$, $d_{unb} = 2.69$		$t(21) = 7.97$, $P < 0.001$, $d_{unb} = 3.23$			
height, cm	144.20 (4.16) (141.70 to 146.60)	173.75 (6.46) (170.33 to 177.17)	147.80 (8.37) (142.70 to 152.82)	170.85 (4.81) (168.31 to 173.54)	$t(13.19) = 1.22$, $P = 0.24$, $d_{unb} = 0.52$	$t(23) = 1.28$, $P = 0.21$, $d_{unb} = 0.49$
Pre–post PHV comparison	$t(20) = 12.44$, $P < 0.001$, $d_{unb} = 5.12$		$t(13.51) = 7.78$, $P < 0.001$, $d_{unb} = 3.38$			
seated height, cm	72.00 (3.89) (69.80 to 74.30)	51.50 (4.10) (49.25 to 53.75)	72.70 (4.67) (69.80 to 75.10)	50.39 (3.15) (48.85 to 52.15)	$t(18) = .36$, $P = 0.72$, $d_{unb} = 0.16$	$t(23) = 0.77$, $P = 0.45$, $d_{unb} = 0.30$
Pre–post PHV comparison	$t(20) = 11.95$, $P < 0.001$, $d_{unb} = 4.92$		$t(21) = 13.69$, $P < 0.001$, $d_{unb} = 5.52$			
body mass index, kg/m^2	17.98 (1.87) (16.94 to 19.17)	22.56 (4.77) (19.87 to 25.16)	19.29 (2.19) (17.94 to 20.55)	19.32 (2.83) (17.86 to 20.92)	$t(18) = 1.43$, $P = 0.17$, $d_{unb} = 0.61$	$t(17.89) = 2.04$, $P = 0.06$, $d_{unb} = 0.81$
Pre–post PHV comparison	$t(14.81) = 3.05$, $P = 0.008$, $d_{unb} = 1.77$		$t(21) = 0.03$, $P = 0.974$, $d_{unb} = 0.01$			
PHV, y	−2.13 (0.63) (−2.51 to −1.77)	0.79 (0.34) (0.60 to 0.98)	−2.09 (0.61) (−2.41 to −1.69)	0.55 (0.67) (0.20 to 0.91)	$t(18) = 0.15$, $P = 0.89$, $d_{unb} = 0.06$	$t(23) = 1.08$, $P = 0.29$, $d_{unb} = 0.01$
Pre–post PHV comparison	$t(20) = 8.35$, $P < 0.001$, $d_{unb} = 5.73$		$t(21) = 9.72$, $P < 0.001$, $d_{unb} = 5.81$			
APHV, y	13.38 (0.33) (13.18 to 13.57)	13.21 (0.34) (13.00 to 13.43)	13.12 (0.38) (12.91 to 13.37)	13.30 (0.32) (13.11 to 13.49)	$t(18) = 1.60$, $P = 0.13$, $d_{unb} = 0.69$	$t(14.19) = 0.88$, $P = 0.39$, $d_{unb} = 0.33$
Pre–post PHV comparison	$t(20) = 1.13$, $P = 0.274$, $d_{unb} = 0.51$		$t(21) = 1.21$, $P = 0.240$, $d_{unb} = 0.52$			

Abbreviations: APHV, age at peak height velocity; d_{unb}, Cohen *d* unbiased as a measure of the effect size ($d_{unb} < 0.50$ constitutes a small effect, $0.50 \le d_{unb} \le 0.79$ a moderate effect, and $d_{unb} \ge 0.80$ a large effect); PHV, peak height velocity. Note: Data are expressed as mean (SD) and 95% confidence interval. Results of the *t* tests for the comparison between the pre-PHV and post-PHV athletes in both the intervention and control groups (groups 1 and 2 and groups 3 and 4) and between the control and intervention in the same maturity group (groups 1 and 3 and groups 2 and 3) are shown.

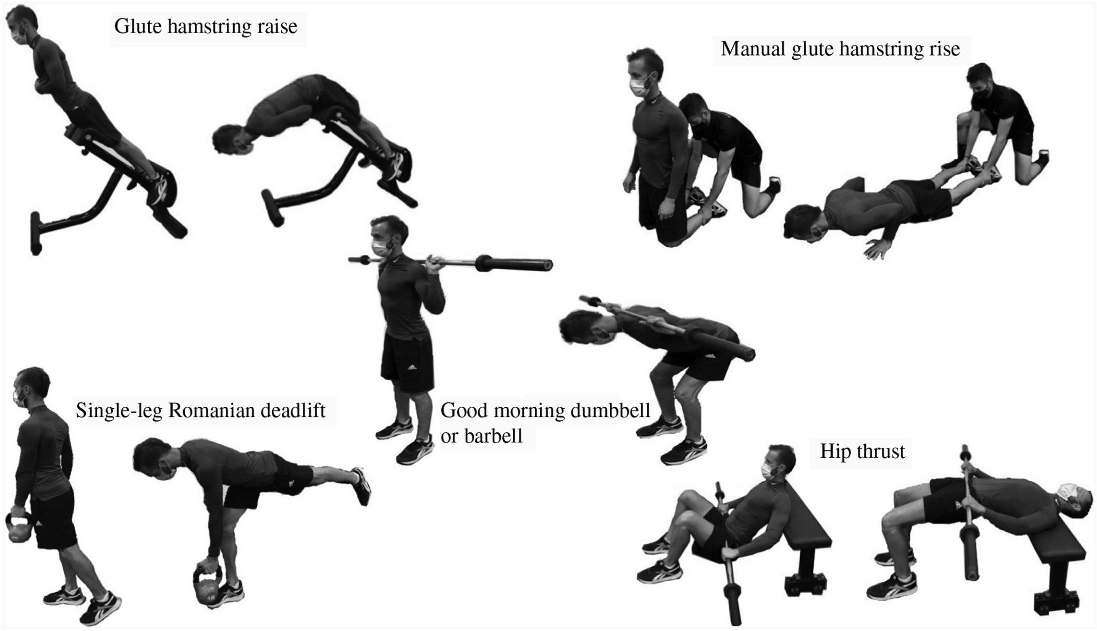

Figure 1 — Exercises focused on the hamstrings and glutes.

Table 2 Design of the Eccentric Training Program

		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Exercises	**Duration, s**	**60% 1RM**	**70% 1RM**	**80% 1RM**	**60% 1RM**	**70% 1RM**	**80% 1RM**
Glute hamstring raise	3–5	2 × 5	2 × 5	2 × 6	3 × 6	3 × 6	3 × 8
Manual glute hamstring rise	3–5	2 × 5	2 × 5	2 × 6	3 × 6	3 × 6	3 × 8
Single-leg Romanian deadlift	3–5	2 × 5	2 × 5	2 × 6	3 × 6	3 × 6	3 × 8
Glute bridge/hip thrust free-weight progressed to dumbbell and barbell	3–5	2 × 5	2 × 5	2 × 6	3 × 6	3 × 6	3 × 8
Good morning dumbbell or barbell	3–5	2 × 5	2 × 5	2 × 6	3 × 6	3 × 6	3 × 8

Abbreviation: 1RM, one-repetition maximum. Note: Data are presented describe the duration of the execution in seconds (only eccentric phase); intensity used each week is presented as a percentage of %1RM, and finally, the volume is presented in sets and (×) repetitions.

Tonbridge, UK), respectively. Body mass index was calculated as weight (in kilograms)/height (in meter square). We conducted the body measurements according to Deurenberg et al (9). At this point, participants completed the standardized warm-up and performed the following tests individually, times were recorded with photocell gates (accuracy of 0.01s; Brower Timing Systems, Salt Lake City, UT) placed 0.4 m above the ground to automatically record the test times. All the researchers were blinded as to the group allocation during the anthropometric and performance measurements. This was achieved using alphanumerical coding for the names of the participants to blind the researchers in charge of the performance measurements. Thereafter, we assessed biological maturity noninvasively as explained in the "Design" section.

CoD Speed. We used the 4 × 5-m shuttle run test and the T-Half test as measurements of the CoD speed.

See Hammami et al (16) and Kibele and Behm (21) for further information on how to conduct the 4 × 5-m shuttle test. The researcher in charge recorded the best time of 2 consecutive tries separated by 3 minutes. Test–retest reliability in similar studies from our laboratory and external (16,21) indicated values between .83 and .95 (intraclass correlation coefficient [ICC]) and 6.4% coefficient of variation [CV]) in pre-PHV and post-PHV athletes, respectively.

We carried out the T-Half test evaluation as previously outlined by Haj Sassi et al (15). This test is useful in determining the speed in directional changes (forward sprinting, left and right shuffling, and backpedaling). Each participant performed 3 tries with a 3-minute rest. We used the best performance for further analysis. Previous research from our laboratory has reported excellent test–retest reliability scores in both pre-PHV (ICC = .89, CV = 4.8%) and post-PHV (ICC = .90, CV = 5.0%) European-handball players (19).

Sprint. We evaluated sprint performance using times of a 10-, 20-, and 30-m run. For such purpose, participants performed a 30-m linear sprint. We recorded the times of the first 10 m, the last 20 m, and the total 30 m. Previous expert literature provides further information on how to perform this test (16,18). Participants performed 2 tries with a 2-minutes rest. We only selected the run with the lowest 30 m time for analysis. The ICC and CV for the test–retest reliability in a previous study from our research group ranged between .87 and .95 and 4.4% and 5.8%, respectively (19).

Statistical Analysis

This study used the software IBM SPSS Statistics (version 26.0; IBM Corp, Armonk, NY). We verified the assumption of normality and homoscedasticity of the dependent variables with the Kolmogorov–Smirnov and Levene tests, respectively. The results from the 4 × 5 and 10 m tests showed a nonnormal distribution ($P \leq .05$), while the rest of the variables showed a normal Gaussian distribution ($P > .05$). Bearing in mind that all of the variables presented homogeneous variances ($P > .05$) parametric tests were used for all the variables (1).

We compared descriptive variables using *t* tests for independent groups. A mixed-model analysis of variance of 3-way repeated measurements with the time (baseline and follow-up) as the within-subject factor, and maturity (pre-PHV and post-PHV) and training intervention (eccentric and control) as the between-subject factors, evaluated differences within the normally distributed variables. All the cases complied with Mauchly sphericity assumption. We reported the effect size as the eta partial squared (η_p^2), where $.01 < \eta_p^2 < .06$ constitutes a small effect, $.06 \leq \eta_p^2 \leq .14$ a medium effect, and $\eta_p^2 > .14$ constitutes a large effect. Where significant differences were detected, we carried out *t* post hoc pairwise comparisons with Bonferroni correction. To report the effect size for post hoc comparisons, we calculated the Cohen *d* with Hedges' corrections to avoid biases due to sample size or SD's difference. Previous research encourages reporting this corrected value as unbiased Cohen *d* (d_{unb}) (5), with $d_{unb} < 0.50$ constituting a small effect, $0.50 \leq d_{unb} \leq 0.79$ a moderate effect, and $d_{unb} \geq 0.80$ a large effect.

To calculate the percentage of variation we used the standard formula: change (%) = ([posttest score − pretest score]/pretest score) × 100. This study accepted a significance level of $P \leq .05$, also, trends of significant difference ($.05 < P < .1$) are identified. We reported all data as means (SDs) and 95% confidence interval.

Results

The analysis of variance showed a significant effect of the time in the T-Half test ($F_{1,41} = 9.19$, $P = .004$, $\eta_p^2 = .18$); 4 × 5-m shuttle run ($F_{1,41} = 55.90$, $P < .001$, $\eta_p^2 = .58$); and 10 m sprint ($F_{1,41} = 8.10$, $P = .007$, $\eta_p^2 = .17$). No significant effect was detected for the 20-m ($F_{1,41} = 0.01$, $P = .924$, $\eta_p^2 = .00$) or 30-m sprint time ($F_{1,41} = 2.95$, $P = .094$, $\eta_p^2 = .07$). The interaction time × maturity showed significant results for the T-Half test ($F_{1,41} = 43.27$, $P < .001$, $\eta_p^2 = .51$) and the 10 m sprint ($F_{1,41} = 10.12$, $P = .003$, $\eta_p^2 = .20$), but not for the 4 × 5-m ($F_{1,41} = 0.15$, $P = .703$, $\eta_p^2 = .01$); the 20-m ($F_{1,41} = 2.25$, $P = .141$, $\eta_p^2 = .05$); or 30-m sprint times ($F_{1,41} = 0.08$, $P = .775$, $\eta_p^2 = .00$). The interaction time × intervention displayed significant effects for the T-Half test ($F_{1,41} = 84.79$, $P < .001$, $\eta_p^2 = .67$); the 20 m ($F_{1,41} = 8.86$, $P = .005$, $\eta_p^2 = .18$); and 30 m sprints ($F_{1,41} = 14.99$, $P < .001$, $\eta_p^2 = .27$), but not for the 4 × 5 m ($F_{1,41} = 1.02$, $P = .319$, $\eta_p^2 = .02$) or the 10 m sprint ($F_{1,41} = 2.25$, $P = .141$, $\eta_p^2 = .05$). Finally, the interaction time × maturity × intervention showed a significant effect for the T-Half test ($F_{1,41} = 30.77$, $P < .001$, $\eta_p^2 = .43$); the 10 m ($F_{1,41} = 37.62$, $P < .001$, $\eta_p^2 = .48$); and 30 m sprints ($F_{1,41} = 4.54$, $P = .04$, $\eta_p^2 = .10$). No significant effect of this interaction was observed for the rest of the tests (4 × 5 m: $F_{1,41} = 0.53$, $P = .471$, $\eta_p^2 = .01$; 20 m: $F_{1,41} = 1.80$, $P = .187$, $\eta_p^2 = .04$).

Table 3 contains the outcomes of each group in all the tests in both baseline and follow-up, with significance and effect sizes of the pre–post comparisons. Table 4 presents the significance and effect sizes for the between-group comparisons of the variation (follow-up minus baseline) in each test.

Discussion

This study aimed to examine the effects of an EHT program in improving CoD speed (CoD) and sprint performance in adolescent male European handball players of different maturity statuses, comparing pre-PHV and post-PHV players. To the authors' knowledge, this is the first study to demonstrate the effectiveness of EHT in improving CoD and sprint performance in preadolescent and adolescent male European handball players and to specifically compare the influence of their maturity status. Due to the novelty in this sense, we will develop this discussion addressing, first, the potential benefits of incorporating EHT to in-season European handball training to improve CoD and sprint performance. Second, we will focus on the potential effects the maturity status of the athletes may have on the training outcomes.

The EHT intervention increased CoD speed and sprint performance in both pre-PHV and post-PHV groups in almost all the tests. Bearing in mind that nonsignificant differences existed between these groups (Intervention pre-PHV and post-PHV; Tables 3 and 4), the study hypothesis could only be partially confirmed. Both control groups yielded no improvements in almost all the tests from baseline to follow-up. This nonimprovement of the performance of both control groups could have been mediated by fatigue (4,26). Only the post-PHV Control Group improved 10-m sprint time, and controls of both maturity groups improved 4 × 5-m shuttle run performance. The sum of these findings aligns with the other 2 studies that examined the effects of eccentric training in a pediatric population (2,16). Hammami et al (16) demonstrated that both 10- ($P = .001$) and 30-m ($P = .007$) sprint performance improved to a greater extent in the intervention group compared with the control in prepubertal weightlifters. Chaabene et al (2) obtained performance improvements in 5-, 10-, and 20-m sprint times (effect size = 0.68–0.82) after 8 weeks of Nordic hamstring exercise in young female European handball players. In this sense, studies on hamstring function during running gait in adults and young females have concluded that the hamstrings work eccentrically to decelerate the forward movement of the foot and the leg in the late forward swing phase of the running cycle (2,28). When sprinting, the deceleration phase shortens, requiring a higher eccentric activation of the hamstrings to compensate for the forward momentum, and the forces that influence the hamstrings may then cause tearing in the muscle–tendon unit (34). The adaptive processes obtained after eccentric training regimens may contribute to improved hamstring activation during the late swing phase, which prepares the muscles to exert an optimal hip-extensor moment during ground contact. Moreover, the fast contraction velocities during EHT may provide an augmented training response, recently termed "synergistic adaptation" (11). Eccentric training produces specific muscular adaptations in young female and male athletes that could be beneficial for CoD performance as well (2,16). For instance, EHT could improve knee joint stability in young soccer players under 19 years old, which facilitates a more efficient transfer of torques through the kinetic chain during CoD (3,7). Also, the increment of the eccentric knee-flexor strength plays an important role in the CoD improvements of female young adult athletes (20).

Table 3 Between- and Within-Group Differences Before and After the 6-Week Intervention

Test	Intervention group	Maturity group	Ref	Baseline	Follow-up	Δ%	Pre–post P value	d_{unb}
	CoD speed							
4 × 5-m shuttle run test, s	Intervention	Pre-PHV	1	8.66 (0.39) (8.44 to 8.89)^{2,4}	8.38 (0.38) (8.18 to 8.63)^{2,4}	**–3.23***	**.001**	**0.67**
		Post-PHV	2	6.27 (0.40) (6.07 to 6.49)^{3}	5.91 (0.52) (5.62 to 6.19)^{3}	**–5.74***$^{,(3)}$	**<.001**	**0.72**
	Control	Pre-PHV	3	8.84 (0.47) (8.56 to 9.12)^{4}	8.59 (0.46) (8.32 to 8.88)^{4}	**–2.83***	**.002**	**0.49**
		Post-PHV	4	5.77 (0.43) (5.55 to 6.02)	5.54 (0.37) (5.35 to 5.75)	**–3.99***	**.002**	**0.54**
T-Half test, s	Intervention	Pre-PHV	1	7.49 (0.37) (7.29 to 7.71)^{4}	7.18 (0.35) (6.97 to 7.40)^{2,3,4}	**–4.14***^{,3,4}	**.001**	**0.79**
		Post-PHV	2	7.82 (0.36) (7.63 to 8.02)^{4}	7.60 (0.30) (7.43 to 7.76)	**–2.81**$^{*,(2),3}$	**.011**	**0.62**
	Control	Pre-PHV	3	7.93 (0.54) (7.59 to 8.23)^{4}	7.94 (0.41) (7.69 to 8.19)	0.13^{4}	.957	0.02
		Post-PHV	4	6.58 (0.39) (6.39 to 6.81)	7.64 (0.30) (7.49 to 7.80)	**16.11***	**<.001**	**2.85**
	Sprint performance							
10 m, s	Intervention	Pre-PHV	1	2.04 (0.19) (1.92 to 2.15)^{2,4}	1.93 (0.10) (1.87 to 1.99)^{2,4}	**–5.39***$^{,(2),3}$	**.001**	**0.66**
		Post-PHV	2	2.16 (0.30) (2.01 to 2.33)^{3}	2.14 (0.29) (1.99 to 2.31)^{3}	–0.93^{3,4}	.473	0.07
	Control	Pre-PHV	3	1.97 (0.12) (1.91 to 2.04)^{4}	2.09 (0.15) (2.00 to 2.19)^{4}	**6.09***^{,4}	**<.001**	**0.81**
		Post-PHV	4	2.27 (0.27) (2.15 to 2.43)	2.12 (0.27) (2.00 to 2.27)	**–6.61***	**<.001**	**0.52**
20 m, s	Intervention	Pre-PHV	1	3.45 (0.29) (3.27 to 3.60)^{2}	3.36 (0.32) (3.16 to 3.53)^{2,4}	–2.61^{4}	.133	0.27
		Post-PHV	2	2.99 (0.42) (2.76 to 3.22)^{3,4}	2.91 (0.43) (2.68 to 3.15)^{3,4}	–2.68^{4}	.138	0.18
	Control	Pre-PHV	3	3.49 (0.19) (3.37 to 3.60)	3.49 (0.31) (3.28 to 3.68)	0$^{(4)}$	.986	0
		Post-PHV	4	3.66 (0.31) (3.49 to 3.81)	3.81 (0.31) (3.65 to 3.96)	**4.10***	**.004**	**0.45**
30 m, s	Intervention	Pre-PHV	1	5.48 (0.29) (5.31 to 5.64)^{4}	5.29 (0.37) (5.04 to 5.50)^{4}	**–3.47***^{,3,4}	**.001**	**0.52**
		Post-PHV	2	5.15 (0.41) (4.95 to 5.40)^{4}	5.05 (0.40) (4.86 to 5.29)^{3,4}	**–1.94***^{,3}	**.050**	**0.23**
	Control	Pre-PHV	3	5.46 (0.24) (5.31 to 5.59)^{4}	5.58 (0.36) (5.37 to 5.82)	**2.20***$^{,(4)}$	**.036**	**0.36**
		Post-PHV	4	5.94 (0.24) (5.81 to 6.06)	5.93 (0.27) (5.79 to 6.07)	–0.17	.887	0.04

Abbreviations: Δ%, percentage of change (negative values indicate improvement and positive values worsening); d_{unb}, Cohen d unbiased as a measure of the effect size ($d_{unb} < 0.50$ constitutes a small effect, $0.50 \le d_{unb} \le 0.79$ a moderate effect, and $d_{unb} \ge 0.80$ a large effect); PHV, peak height velocity; ref, reference number of each group. Note: Data are expressed in seconds as mean (SD) and 95% confidence interval. Sample size of each group: intervention pre-PHV (n = 10), intervention post-PHV (n = 12), control pre-PHV (n = 10), and control post-PHV (n = 13).

Statistically significant differences ($P < .05$) are identified with "*" and in bold for the within-group comparisons and with numbers for the between-group comparisons; also, trends of significant difference ($.05 < P < .1$) are identified with numbers between brackets. ^{1,2,3,4}Statistically significant differences ($P < .05$) with the group 1, 2, 3, or 4, respectively.

Table 4 Post Hoc Between-Group Comparisons of the Percentage of Change ([Follow-up − Baseline/Baseline] × 100) on Each Dependent Variable

Groups being compared		CoD speed		Sprint performance		
		4 × 5-m shuttle run	T-Half test	10 m	20 m	30 m
1–2	Intervention pre-PHV–intervention post-PHV	*$P = .123$, $d_{unb} = 0.50$*	*$P = .456$, $d_{unb} = 0.46$*	$P = .051$, $d_{unb} = 1.02$	*$P = .922$, $d_{unb} = 0.04$*	*$P = .220$, $d_{unb} = 0.71$*
1–3	Intervention pre-PHV–control pre-PHV	*$P = .871$, $d_{unb} = 0.12$*	**$P = .020$, $d_{unb} = 0.89$**	**$P < .001$, $d_{unb} = 1.79$**	*$P = .316$, $d_{unb} = 0.31$*	**$P < .001$, $d_{unb} = 1.28$**
1–4	Intervention pre-PHV–control post-PHV	*$P = .649$, $d_{unb} = 0.26$*	**$P < .001$, $d_{unb} = 5.28$**	*$P = .314$, $d_{unb} = 0.38$*	**$P = .006$, $d_{unb} = 1.32$**	**$P = .014$, $d_{unb} = 1.40$**
2–3	Intervention post-PHV–control pre-PHV	$P = .088$, $d_{unb} = 0.59$	$P = .083$, $d_{unb} = 0.67$	**$P = .001$, $d_{unb} = 1.59$**	*$P = .253$, $d_{unb} = 0.44$*	**$P = .005$, $d_{unb} = 1.01$**
2–4	Intervention post-PHV–control post-PHV	*$P = .236$, $d_{unb} = 0.37$*	**$P < .001$, $d_{unb} = 5.59$**	**$P = .002$, $d_{unb} = 1.73$**	**$P = .003$, $d_{unb} = 2.36$**	*$P = .176$, $d_{unb} = 0.89$*
3–4	Control pre-PHV–control post-PHV	*$P = .530$, $d_{unb} = 0.44$*	**$P < .001$, $d_{unb} = 3.04$**	**$P < .001$, $d_{unb} = 2.35$**	$P = .072$, $d_{unb} = 0.72$	$P = .093$, $d_{unb} = 0.58$

Abbreviations: CoD, change of direction; d_{unb}, Cohen d unbiased as a measure of the effect size ($d_{unb} < 0.50$ constitutes a small effect, $0.50 \le d_{unb} \le 0.79$ a moderate effect, and $d_{unb} \ge 0.80$ a large effect); PHV, peak height velocity. Note: Statistically significant differences ($P < .05$) are highlighted in bold font, tendencies ($.05 < P < .1$) in roman, and, finally, nonsignificant differences ($P > .1$) are identified in italic. Group 1: intervention pre-PHV; group 2: Intervention post-PHV; group 3: control pre-PHV; group 4: control post-PHV.

Due to these aforementioned facts, strength and conditioning professionals may consider EHT as a more specific modality to train the deceleration and stabilization of the hips and knees during CoD and sprint tasks in several sport disciplines. Promoting such changes early on during athletic development is important in creating effective CoD and sprint performance, so more sophisticated movement patterns can be achieved through and after puberty. However, recent research has identified that growth and maturation (22) and the training method (11) can both impact the training response in youth. Specifically, maturity influences the natural development (31) and trainability of sprinting (30) and CoD ability in adolescents (24), and therefore the rate at which athletes are experiencing maturation may play a role in the training response.

Concerning the effect of the maturity status on the intervention outcomes, it is worth mentioning that post-PHV individuals obtained significantly lower test times (both baseline and follow-up) in all the tests except in the T-Half test and the 10 m sprint. However, focusing exclusively on the pre–post intervention changes (percentage of variation), the current study revealed that nonsignificant differences existed between pre-PHV and post-PHV individuals. These findings highlight the importance of an EHT stimulus for players that are both pre-PHV and post-PHV to enhance the natural increase in neural coordination and central nervous system maturation that takes place during childhood (25). Furthermore, and concerning the within-group analysis, the Intervention pre-PHV Group showed similar improvements in the 4 × 5 m, T-Half, 10 m, and 30 m (all effect sizes between 0.52 and 0.79), being the improvements in the 20-m sprint nonsignificant. On the other hand, the post-PHV Group improved their performance to a larger extent in the 4 × 5 m and T-Half test (effect sizes of 0.72 and 0.62, respectively) compared with the 30 m sprint (effect size of 0.23), the improvements of this group in the 10 and 20 m sprints were nonsignificant. The disparities in the structure of the tests performed may explain such small differences. Specifically, the T-Half test consists of shuffling movements and backward running, which are both absent in the 4 × 5-m shuttle run. More importantly, the T-Half test involves several moments of "zero velocity" (ie, stop-and-go movement patterns), while the 4 × 5-m shuttle run test includes shuttle movement patterns and no moments of "zero velocity." In this sense, the 10-m sprint measures acceleration while the 20 and 30 m sprints require maximal speed and resistance. Considering that the 4 × 5-m shuttle run and T-Half were the tests in which the post-PHV Group improved more, we could suggest that the high neural demand of rapidly changing direction without stopping required a stimulus that coincided with the natural adaptive response of the post-PHV participants resulting in growth and maturation (24). Developmentally, post-PHV players experience morphological changes that facilitate force generation (eg, increased motor unit size and pennation angles) in addition to continued neural adaptations as a consequence of cognitive maturation (25). Therefore, future studies investigating the effect of cognitive maturity on preplanned performance development are warranted.

Some limitations should be listed before concluding the article. First, and although 45 participants could be an appropriate sample size for such a design, the post hoc power analyses performed with G*Power (version 3.0) (13) showed a power (1–β) of 0.80 with an effect size (f [V]) of 0.52 and an α of .05. Future studies should increase the sample size of each group to increase this statistical power. Also, although all the athletes' habits remained unchanged during the intervention, it would have been interesting to take follow-up anthropometric measurements of the athletes to evaluate if these parameters could have influenced the outcomes in the test. Future studies should evaluate this and other potential mechanisms (eg, physiological parameters, muscle architecture, power, and/or activation) that could have mediated the improvements of the athletes and differences between maturity groups.

Practical Applications

The results show that a 6-week EHT is enough to increase CoD and sprint performance in both pre-PHV and post-PHV athletes. This training methodology can be implemented along with the usual training regimen in pre-PHV athletes to build a foundation for more sophisticated movement patterns in later maturity stages.

Considering that responses to training stimuli can differ within the physical development of athletes (11,30,37), it would be interesting to examine in the future such effects in the same athletes. Future studies could examine the effects of EHT in young athletes accounting for changes such as muscle action and architecture, and further physical components such as balance and lower limb asymmetry in the perspective of injury prevention.

Conclusion

The present study is the first to examine the effects of an EHT program in combination with regular European handball training on sprint and CoD performance in young male European handball players of different maturity statuses. The results suggest that EHT can enhance CoD and sprint performance in young athletes regardless of their maturity status. The contents presented in this study may help practitioners working with male preadolescent and adolescent European handball players to implement the EHT into their training programs early in order to enhance sprint and CoD performance.

All the contents presented in this manuscript have been carried out in parallel with the athletes' regular handball training, and therefore, caution should be applied when extrapolating the results to different sports. However, athletes practicing team sports with similar features as European handball (eg, futsal, basketball) could benefit from EHT to improve their CoD and sprint performance.

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