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The effects of 6 weeks eccentric training on Speed, Dynamic Balance, Muscle Strength, Power and Lower Limb Asymmetry in Prepubescent Weightlifters

RAOUF HAMMAMI[1], MICHAEL J DUNCAN[2], AMMAR NEBIGH[1], HANEN WERFELLI[1] & HAITHEM REBAI[1]

[1]Research Unit: "Education, Motricity, Sports and Health" (UR 15JS01), Higher Institute of Sport and Physical Education of Sfax, University of Sfax, Sfax, Tunisia.

[2]Centre for Sport, Exercise and Life Sciences, Coventry University, Coventry, UK

Running Head: Eccentric training

Address for correspondence:

Prof Michael J. Duncan, Centre for Sport, Exercise and Life Sciences, Coventry University, Coventry, UK. E-mail: michael.duncan@coventry.ac.uk

Running Head: Eccentric training

This study examined whether 6 weeks of twice-weekly in-season hamstring eccentric training would enhance selected performance-related abilities in prepubescent male weightlifters. Twenty elite weightlifters (11.1 ± 0.8 years) were randomly split into an eccentric training intervention group (INT n = 10) or a control group (CON) that maintained their standard in-season regimen (n = 10). Pre and post intervention Speed, Dynamic Balance, Muscle Strength, Power and Lower Limb Asymmetry were assessed. ANCOVA controlling for maturation was used to determine any differences in the performance variables. There were no significant changes in muscle strength, dynamic balance or lower limb asymmetry (all $P < 0.05$) because of the intervention. Both 10m ($P = 0.001$) and 30m ($P = 0.007$) sprint speed and agility ($P = .049$) improved to a greater extent in INT compared to the CON group. Similar results were evident for the standing long jump ($P = 0.015$) and 3 hop test ($P = 0.004$) were performance improved to a greater magnitude in INT compared to CON groups. This study suggests that eccentric training, undertaken twice weekly for 6-weeks result in positive changes in sprint speed, change of direction speed and power performance, but not muscle strength, dynamic balance or lower limb asymmetry in prepubertal weightlifters.

Keywords: Resistance Exercise; Change of Direction; Horizontal Jumps; Youth; Maturation

INTRODUCTION

Several organizations such as the United Kingdom Strength and Conditioning Association, the Canadian Society of Exercise Physiology and the NSCA have also advocated that advanced exercises such as eccentric strengthening exercise can be incorporated into a youth training program to enhance athletic performance (3, 7) and prevent injuries (1). It has previously been shown that eccentric strength training is more effective than single mode concentric or combined concentric-eccentric training in improving muscle power, muscle mass, speed, and stretch-shortening cycle activities (12, 14). However, similar intervention examining whether eccentric training interventions influence other aspects of athletic performance such as balance and lower limb asymmetry have yet to be examined. Given the importance of both balance and lower limb asymmetry on athletic performance such an investigation appears warranted.

Previous research has demonstrated that enhancement of agility performance was associated with eccentric knee-flexor strength (7, 25). Additionally, it has been demonstrated that knee-flexors play a significant role in producing horizontal propulsive force during the stance phase through hip extension during sprint tasks (30). In this regard, hamstring eccentric exercise is widely used in youth training program and easily performed on the pitch or in the gym without any additional equipment (1, 5). A recent review of Chaabene et al., (7) reported small- to large-sized effects (d = 0.46–1.31) of strength training with accentuated eccentric muscle actions on change of direction (CoD) speed performance in athletes. Furthermore, five cross-sectional studies revealed statistically significant moderate- to large-sized correlations (r = 0.45–0.89) between measures of eccentric muscle strength and CoD speed performance in adult female (24, 39) and male (5, 10, 39) athletic populations. Only one study, Chaabene et al., (7) has examined the effectiveness of 8 weeks Nordic Hamstring Eccentric training on improving physical performance in young female handball players. The authors showed moderate performance improvements in 5 m, 10 m, 20 m speed (effect-size [ES] = 0.68-0.82), T-test (ES=0.74), and countermovement jump (CMJ) (ES=0.85). Trivial-to-small improvements were observed for repeated sprint ability (RSA) (ES=-0.06-0.35) and agility performance (T-test [ES=0.71]), small (5 m [ES=0.46], and RSA [ES=0.00]). The research to date on this topic has largely focused on adolescent and post pubertal females. Given the need to understand if such training modalities are appropriate throughout different stages of maturation it is important, in terms of guiding strength and conditioning practice to also establish if eccentric training is effective in a prepubescent population.

In the context of weightlifting practice which requires a high level of strength and balance capabilities (8) and given that balance and coordination are not fully developed with children, it would be advantageous to be equally balanced and symmetrical at performing powerful specific actions such as the snatch and jerk etc. With this mind, children weightlifters are asked to land off either limb in response to an appropriate stimulus. In addition, previous research suggested that the magnitude of asymmetry are task dependent (21). In this context, it has been suggested that a range of asymmetries ≥ 10 % appeared typical during a running (26, 28), isokinetic strength (9), change of direction (11, 35) and a variety of jumping-based tasks (4) with youth population.

Furthermore, youth athletes presented individual physiological changes (e.g., hormonal, central nervous system myelinization) which are likely contributing factors to altered different types of adaptation in motor control strategies (20). Consequently, knowledge of whether bilateral asymmetry have an eventual impact on athletic performance would be essential for effective programming and improving athletic performance with weightlifter children with an immature neuromuscular system (3). Available literature have focused on bilateral asymmetries in multiple testing modalities including muscle strength (2, 37), and power (4, 11). One such option modality most likely used in testing is the jump protocols because of their ease of implementation (4) which is an important consideration due to the reduced training age in youth athletes (4). Bishop et al., (4) showed significant negative relationships between horizontal asymmetries during the triple hop test and horizontal jump performance (r = -0.47 to -0.58); and between vertical asymmetries during the single leg countermovement jump (SLCMJ) and vertical jump performance (r = -0.47 to -0.53) with nineteen elite, youth, female soccer players of 10 years of age. The research conducted to date is limited due to its cross sectional nature and that it has only been examined in female athletes. To the authors' knowledge, no study has examined the chronic effect of hamstring eccentric training on improving balance, sprint, agility and muscle strength and power; and on reducing lower limb asymmetry in prepubescent children with strength and balance deficit that can be lead to an injuries rates (34).

Hence, this study aimed to investigate the effects of 6 weeks in-season hamstring eccentric training program on speed (10 and 20-m linear sprint times, agility (4 × 5-m shuttle run), dynamic balance (Y-Balance), muscle strength (1 RM) and power (Standing Long Jump (SLJ), 3 Hop Jump and Single leg Jump) and lower limb asymmetry in prepubescent weightlifters.

METHOD

Experimental Approach to the Problem

The current study examined whether 6 weeks of twice-weekly in-season hamstring eccentric training would enhance selected performance-related abilities in prepubescent male weightlifters relative to their peers who continued to follow their customary in-season weightlifting training regimen. A group of 20 elite players volunteered for random assignment to either an eccentric training group (n = 10) or a control group that maintained their standard in-season regimen (n = 10). The test protocol included assessments of sprint performance (times over 5 and 30 m), a change-of-direction test (4 × 5-m shuttle Run), a Standing Long Jump (SLJ), a 3 Hop Jump Test, a Single Leg Hop Jump Test, a Lower Limb Asymmetry (Interlimb Imbalance and Symmetry Index), a Dynamic balance performance (Y-Balance score), and a Dynamic Strength test (1 RM).

Subjects

This study was conducted on 20 prepubertal weightlifters who were members of the weightlifting promotion center (age: 11.1 ± 0.8 years, body mass: 39.8 ± 6.0 kg, body height: 146.2 ± 6.5 cm, sitting height: 72.3 ± 4.2 cm; leg length: 73.8 ± 4.1cm, PHV: -2.1 ± 0.6 and APHV: 13.2 ± 0.4 years). Anthropometric characteristics are presented in Table 1. Thereafter, biological maturity was assessed non-invasively by incorporating measures of chronological age and body height into a regression equation able to predict biological age from PHV (29). The equation has previously been validated for boys and presents a standard error of estimates reported as 0.542 years (29). With this equation, all players were categorized as prepubescent. The respective equation is reported below: Maturity offset=−7.999994 + (0.0036124 × age [yrs] × height [cm]).They were involved in systematic weightlifting training for at least 1.4 ± 0.5 years. At the time of this study, they trained 2-3 times a week (90 minutes per session). It is important to note is that all the athletes had routinely performed back squats as part of their regular resistance training regimen for a minimum of 1 year before the study, and therefore were highly familiarized with this exercise. Subjects were randomly assigned between experimental and control groups. They were well matched in terms of their initial baseline athletic performance, anthropometrics and maturation; a Student’s nonpaired t-test showed no statistically significant intergroup differences The study was conducted according to the Declaration of Helsinki, and all athletes received a clear explanation of the study, including the risks and benefits of participation; written informed consent was obtained from their parents/responsible adults prior to testing, and the athletes themselves agreed to participate in the study. The Ethical Board of **** hidden for reviewing *** approved the investigation.

Table 1 here

Procedures

All procedures were carried out during the second half of the season (March-May 2018). Before the commencement of the study and prior to the initiation of testing, all players completed a two-week orientation period (three sessions/week) to become familiar with the general environment, form and technique of each fitness test used to evaluate sprint, power, agility, and balance technique for each training exercise, equipment, and the experimental procedures. During this time, the young weightlifters received consistent instructions on proper technique for the eccentric strength exercise, and landing from Certified Strength and Conditioning Specialists. Each player's height and body mass were collected using a wall-mounted stadiometer and electronic scale, respectively. The sum of skinfolds was monitored with Harpenden skinfold calipers (Baty International, West Sussex, England). Body measurements were conducted according to Deurenberg et al. (13) who reported similar prediction errors between adults and young adolescents. Performance testing occurred before and following the 8-week training period. The testing protocol included assessment of sprint (10, 20 and 30-m), balance (Y-Balance score), muscle strength (1RM) and power (SLJ, 3 Hop Jump and Single leg Jump) and lower limb asymmetry (Inter-limb Imbalance and Symmetry Index).

Dependent Variables

Sprint

Sprint ability was evaluated by a linear 10-m sprint (acceleration), and 30-m sprint (speed) (32). For each test, two seconds before the assessment, participants were asked to take the start position, with the front foot placed 5 cm before the first timing gate and await the start signal for the next sprint. Time was recorded using photocell gates (Brower Timing Systems, Salt Lake City, UT, USA) placed at the start-finish point and on the 10-m or 30-m lines, respectively, approximately 0.4 m above the ground, and with an accuracy of 0.001 s. Both sprint tests were performed twice, separated by at least 2 min of passive recovery. The best performance was recorded and used for further analysis. In addition, for the 30-m sprint, averages were calculated for 10 m (the first linear 10 m from the start point) and the 20-m flying time (the time for the split between the 10-m and 30-m lines). The intra-class correlation coefficient for test-retest reliability and typical error of measurement for the 10-m sprint test were 0.98 and 5.2%, respectively (20).

Agility

Agility was evaluated with the 4×5-m shuttle run test (40). The test consisted of constant direction changes that players had to make. Five cones were set up 5 m apart (Figure 1). The players stood with their feet apart and the cone between their legs. Every player started after the sound signal and ran 5 m from point A to point B. After reaching point B, he made a 90° turn to the right and then shuffled 5 m to point C. At point C, he made a 90° turn and ran to point D, where he made an 180° turn and ran on to point E (the finish line). The intra-class correlation coefficient for test-retest reliability and the coefficient of variation (cv) of the agility test with youth test were 0.97 and 4.3 %, respectively (40). Recognizing that the aforementioned work (40) focused on 19 year old soccer players, we also determined test-retest reliability and cv in our current sample which indicated acceptable values of 0.83 and 6.4 respectively.

Horizontal Jumps

For the Standing Long Jump, athletes stood on two legs behind the starting line and were instructed to push off vigorously and jump forward as far as possible. The distance jumped was measured in centimetres using a metal tape measure from the start line at take-off to the position of the heel on landing.

With the 3 hop test, a tape measure was fixed to the ground, perpendicular to the starting line. Participants stood on the dominant leg, behind the starting line. The leg used to kick a soccer ball identified the dominant leg. They performed three consecutive maximal forward hops on the same (dominant) limb. Arm swing was allowed. Each participant was instructed to sink to a self-selected depth as quickly as possible and jump as far forward as possible and land on 2 feet. The investigator measured the distance hopped from the starting line to the point where the heel struck the ground on completing the third hop.

Test retest reliability for the SLJ and the 3 Hop J Tests demonstrated higher ICC ranged from: 0.91 (0.83–0.96) to 0.92 (0.87-0.95) with an SEM from 1.78 to 2.09 (20).

With the Single Leg Hop Test in which the subject was instructed to stand on one leg and to position his toes to a mark on the floor. The subject was then instructed to hop forward as far as possible and to land on the same leg. The subject was allowed to swing his arms freely as he jumped. The distance, in centimeters, was measured from the toe in the starting position to the heel where the subject landed. A hop was only regarded as successful if the subject was able to keep his foot in place while balancing on one leg (i.e. no extra hops was allowed) until an investigator had marked where the subject had landed. Failure to do so resulted in a re-hop. The test was performed until three successful hops were obtained for each leg, with the starting order of the right or the left leg randomly assigned to the subjects. Each subject was given two practice trials before the test. Intra-class correlation coefficients and the cv ranged from 0.81 to 0.88 and 3.94 to 4.18, respectively for the single hop test conditions, indicating that all tests were reliable in youth athletes (4).

Muscle Strength

Lower-body strength was assessed with a 1RM test of the Back Squat as reported by Keiner et al. (25). Before attempting a 1RM, subjects performed three submaximal sets of 1–6 repetitions with a light to moderate load. Subjects then performed a series of single repetitions with increasing loads. If the weight was lifted with the proper form, it was increased by approximately 1–2 kg, and the subject attempted another repetition. The increments in weight were dependent on the effort required for the lift and became progressively smaller as the subject reached 1RM. Failure was defined as a lift falling short of the full range of motion on at least 2 attempts spaced at least 2 minutes apart. The 1RM was typically determined within about 6–8 trials. Throughout all testing procedures, an instructor-to-subject ratio of 1:1 was maintained, and uniform verbal encouragement was offered to all subjects. Test-retest reliability was high for the back squat in youth athletes with an ICC value of 0.99 (25).

Lower Limb Asymmetry

In the present study, bilateral asymmetry was calculated according to the performance measure during the Single Leg Hop Test. A negative sign (-) was arbitrarily assigned when the left leg was the stronger one, and a positive sign (+) was used when the right leg was the stronger one. In the literature (22), relative lower-limb inter-limb asymmetry (LLIA) is calculated by the formula (stronger leg – weaker leg)/stronger leg × 100. Similarly a symmetry index (SI) was also calculated by the formula: strong leg/weak leg × 100. Lower limb asymmetry test–retest intra-class correlation coefficient was 0.91 (0.85–0.94), and typical error was 2.4% in youth athletes (22).

Dynamic Balance

With the Y-Balance test, and for each trial, subjects placed their hands on their hips and began in a unilateral stance with the most distal aspect of their great toe behind the line on the centre of tape. Distances were then recorded by pushing the target reach indicator in the 3 directions and trials were performed on dominant leg. Throughout, subjects were required to keep the heel of the non-reach leg on the testing platform, maintain balance in a single leg stance, and return the reach foot back to the start prior to attempting the next direction. Also, no visible kicking of the target reach indicator was permitted. Maximal reach distances were recorded to the nearest 0.5 cm marker on the Y-balance kit. Balance performance was calculated as the composite score (MADX [%]), obtained by dividing the sum of the maximal reached distances in the three directions by three times the length of the lower limb (LL; measured from the most distal end of the anterior superior iliac spine to the most distal end of the medial malleolus of each limb), then multiplied by 100: MADX %= $\{[(A + PM + PL) / (LL \times 3)] \times 100\}$. Excellent test-retest reliability has been reported for the Y-Balance test in all three directions with ICC values ranging between 0.89 and 0.93 (20).

Training program

The training intervention consisted of a progressive 6-week eccentric strengthening program for the hamstrings muscles using the eccentric hamstring training (EHT) (Table 1). The EHT consisted of five exercises: Glute-hamstring raise, Manual glut-hamstring rise, Single leg romanian dead lift and Good morning dumbell or barbell. The training intervention consisted of two sessions per week with 3-to-5 sets per session and 10-to-12 repetitions per set. A progressive loading increased from 60% 1RM during the first week, 70% 1 RM during the second week in order to attempt 80% 1 RM during the third week. Load decreased to 60% RM during the fourth week and finally increased to 70°/° RM to 80°/° RM during the five and the six week, respectively (Table 2). During exercise execution, participants were instructed to keep a straight torso and slightly flexed hips during the entire range-of-motion. Each participant was instructed to keep controlling the movement as much as possible through a full eccentric hamstrings activation from the start to the end of the set. Each participant alternated between performing one set and assisting their partner in doing the same (7). During each eccentric exercise, participants were lowered the resistance and therefore were instructed to keep a straight torso and slightly flexed hips during the entire range-of-motion. Additionally, they were asked also to forcefully push their body back to the start position to minimize hamstrings muscles activation in the concentric mode (31). Participants were instructed to return the load using as little effort as possible to minimize loading in the concentric phase. The between-session recovery time was 48-h. The CG followed its weightlifting training. For both groups, no training routine change during the intervention period was permitted. This included mainly avoiding specific eccentric hamstrings strength exercises. The overall weightlifting training load was comparable between both groups. This is because they were following similar weightlifting training routines consisting of 5-to-6 sessions per week with 60-to-90 min each. All training sessions were fully supervised by a certified strength and conditioning coach. The control group followed its weightlifting training.

Table2 here

Statistical Analysis

Recognizing there were no significant differences between any of the dependant variables at baseline between intervention (INT) and control (CON) groups, any changes in the dependant variables pre-post intervention were examined using a series of 2 (pre-post) X 2 (INT vs CON) repeated measures analysis of covariance (ANCOVA), controlling for age at peak height velocity (APHV) as the covariate. Partial η^2 was used as a measure of effect size. Where any significant differences were found post hoc pairwise comparisons (Bonferroni adjusted) were employed to examine where the differences lay. The Statistical Package for Social Sciences (SPSS, Version 25, IBM Corp, Armonk, New York) was used for all analysis.

RESULTS

Mean ± SD and 95% confidence intervals (CIs) for dependant variables pre to post intervention in INT and CON groups are presented in Table 3.

Table 3

Sprint Speed

In regard to sprint speed results indicated significant group X pre-post interactions for 10m ($F_{1,17} = 15.5$, $P = 0.001$, $P\eta^2 = 0.478$) and 30m sprint speed times ($F_{1,17} = 9.245$, $P = 0.007$, $P\eta^2 = 0.352$). Bonferroni post hoc pairwise comparisons indicated that, for 10m speed, participants got significantly faster pre-post (P= 0.022) while there was also a significant increase in sprint time (i.e., poorer performance) for the CON group (P= 0.012). However, for 30m sprint time, performance improved (ie sprint times were shorter) for the INT group (P= 0.003) but there was no change in sprint times for the CON group (P= 0.230).

Figure 2 Here

Figure 3 Here

Agility

There was also a significant group X pre-post interaction ($F_{1,17} = 4.485$, $P = 0.049$, $P\eta^2 = 0.209$) for agility performance. Agility time was significantly lower post intervention (P = 0.004) for the intervention group, compared to the control group where no significant pre-post change was evident (P= 0.973).

Figure 4 Here

Horizontal Jumps

For standing long jump, results from ANCOVA controlling for APHV indicated a significant group X pre-post interaction ($F_{1,17} = 7.4$, $P = 0.015$, $P\eta^2 = 0.303$). Bonferroni pairwise comparisons indicated that standing long jump performance significantly increased pre-post for the INT group (P= 0.0005) but not the CON group (P= 0.204).

Figure 5 Here

For the 3 hop test there was also a significant group X pre-post interaction ($F_{1,17}$ = 11.335, P= 0.004, $P\eta^2$ =.4). Bonferroni pairwise comparisons indicated that SLJ performance significantly increases pre-post for the INT group (P= 0.002) but not the CON group (P= 0.109).

Figure 6 Here

Muscular strength

For 1RM values there were no significant higher order interaction or main effects for pre-post or group, nor was APHV significant as a covariate (all P> 0.05).

Lower limb asymmetry and dynamic balance

Results from ANCOVA indicated no significant interaction, main or covariate effects on inter-limb imbalance (all P> 0.05) or symmetry index (all P> 0.05). Likewise, there were no significant interaction, main or covariate effects for anterior reach, posterior-medial reach left and posterior-medial reach right (P> 0.05). There were also no significant interaction of main effects for Y-Balance composite scores (P> 0.05).

DISCUSSION

The current study sought to examine the effect of 6 weeks in-season hamstring eccentric training program on Speed (10 and 20-m linear sprint times), Agility (4 × 5-m shuttle run), Dynamic Balance (Y-Balance), Muscle Strength (1 RM) and Power (SLJ, 3 Hop Jump and Single leg Jump) and lower limb asymmetry in prepubescent weightlifters. This is the first study to date to examine this modality of exercise on athletic performance variables in this population and as such the data presented here represent an original contribution to the literature.

The results of the current study suggest that, controlling for APHV, 6-week eccentric training program resulted in significant improvements in 10m and 30m sprint speed, agility performance and horizontal jump performance in both the standing long jump and 3 hop test. Such findings align with the only other study to examine effects of eccentric exercise training in a pediatric population (7). The results of the current study also agree with prior work reporting increases in muscle power, speed and stretch-shortening cycle activity in adult populations (12, 14). Of note, in the current study 1RM strength did not significantly improve pre to post in the eccentric training group compared to the control group. Although prior work has noted changes in strength (12, 14) as a consequence of eccentric training in adults, the lack of significant change in 1RM strength in the current study is not unexpected due to the prepubertal status of the participants involved. This underlines the fact that children should not be considered as small adults and assuming the same magnitude of change from training interventions in children as in adults may be erroneous due to the different types of adaptation in motor control strategies from training in children (20). Age at peak height velocity was also not significant as a covariate in any of the analysis, indicating that any changes in dependant variables as a consequence of the training program were not associated with stage of maturation. It is important to consider whether or not the training program should be considered successful in the current study, given the lack of change in strength performance. There are qualitative musculometabolic differences between children and adults (16) and an assumption that training programs might produce the same effect in children as in adults is erroneous. The lack of improvement in 1RM performance should not be taken that the eccentric program employed in the present study is not successful or useful. Rather, the results presented here demonstrate that eccentric training in this population is successful in enhancing other attributes related to overall athletic performance such as sprint speed, change of direction speed and power performance. In the context of athlete development, for children such a program as used here, could be considered useful in building overall athletic attributes first, rather than strength alone.

The sample employed in the present study were junior weightlifters who had a minimum of one years experience in weightlifting. As such they represent a specifically trained group and the results of the present study may not necessarily be transferable to other athletic groups. For example the results of the current study indicated that the eccentric training programme had no effect on dynamic balance or lower limb asymmetry. However, the range of lower limb asymmetries in the present study were low, and lower than the previously reported figures for runners of$\geq$ 10 % (28, 36). The training process for weightlifting in prepubescent athletes emphasises movement in a balanced and symmetrical manner. Coupled with the age of the children involved it is less likely that asymmetrical movement patterns had been developed. Whether the eccentric training programme used in the present study is effective in improving dynamic balance and reducing lower limb asymmetry in children who have significant existing lower limb symmetry or dynamic balance issues would be a useful. Given that balance and coordination are not fully developed in children (19), the implementation of 6 weeks of eccentric hamstring training into youth resistance training is not efficient in improvement of balance performance and reducing lower limb asymmetry in children.

In regard to sprint and CoD performance, the significant decrease in sprint time after 6 week eccentric hamstring training documented in the present study are complemented by similar findings by Chaabene et al. (6) in a sample of 15 years old female handball players. To the authors' knowledge, no study has previously addressed the effects of eccentric hamstring training on speed performance in prepubertal weightlifters. As such the data presented here are novel. Krommes et al. (27) observed improvements in sprint performance (i.e., 5 m [Δ7.5%] and 10 m [Δ4.6%] sprint time) after 10 weeks of training when compared with an active control group. Studies on hamstring function during running gait 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 (6, 31). When sprinting, the deceleration phase shortens, requiring a higher eccentric activation of the hamstrings to compensate the forward momentum, and the forces that influence the hamstrings may then cause tearing in the muscle–tendon unit (18). These adaptive processes after eccentric training regimens may have contributed to improved hamstrings activation during the late swing phase, which prepares the muscles to exert an optimal hip extensor moment during ground-contact.

Moreover, the observed CoD performance enhancement in young can be attributed to the effects of eccentric hamstring training given the established association between eccentric knee flexor strength and CoD performances. Recent cross-sectional studies revealed statistically significant moderate- to large-sized correlations ($r = 0.45$–0.89) (26, 33) and small- to large-sized effects ($d = 0.46$–1.31) (10, 38, 41) between measures of eccentric muscle strength and CoD speed performance in athletic populations. Eccentric strength training produces specific muscular adaptations that could be beneficial for CoD speed performance (7). This modality can be considered as a more specific modality that especially needed to decelerate and stabilize the body during CoD tasks. Moreover, eccentric hamstrings strength could also help to improve knee joint stability during the moment of CoD, thus facilitating a more efficient transfer of torques through the kinetic chain (25). Establishing such changes in sprint and CoD performance in prepubertal athletes is important in creating effective movement early on in during athletic development so more sophisticated movement patterns can be established through puberty. Consequently, the results presented here evidence the potential for eccentric training to positively enhance sprint and CoD performance in pediatric athletes.

Practical Applications

The results of this study suggests that eccentric training, undertaken twice weekly for 6-weeks result in positive changes in sprint speed, change of direction speed and power performance in prepubertal weightlifters. However, eccentric training was not effective in enhancing dynamic balance or lower limb asymmetry. Age at peak height velocity was not significantly associated with any of the changes in sprint speed, change of direction speed, power performance dynamic balance or lower limb asymmetry. In prepubertal athletes accounting for maturation does not seem to influence performance gains from eccentric training. Using eccentric training in the manner evaluated in the current paper is therefore an effective means for coaches and practitioners to enhance in-season speed, power and change of direction abilities in young weightlifters.

REFERENCES

1. Al Attar WSA, Soomro N, Sinclair PJ, Pappas E, Sanders RH. Effect of injury prevention programs that include the nordic hamstring exercise on hamstring injury rates in soccer players: a systematic review and meta-analysis. *Sports Med 47*(5): 907-916, 2017
2. Bailey CA, Sato K, Burnett A, Stone MH. Force-production asymmetry in male and female athletes of differing strength levels. *Int J Sports Physiol Perf 10*: 504-508, 2015
3. Behm DG, Faigenbaum AD, Falk B, Klentrou P. Canadian Society for Exercise Physiology position paper: resistance training in children and adolescents. *Appl Physiol, Nutr Metab 33*: 547-561, 2008.

4. Bishop C, Read P, McCubbine J, Turner A. Vertical and Horizontal Asymmetries are Related to Slower Sprinting and Jump Performance in Elite Youth Female Soccer Players. *J Strength Cond Res* e-pub ahead of print, 2018.
5. Chaabene H. Change of Direction Tasks: does the eccentric muscle contraction really matter. *Sci Pages Sports Med* 1:1–2, 2017
6. Chaabene H, Negra Y, Moran J, Prieske O, Sammoud S, Ramirez-Campillo R, Granacher U. Effects of an Eccentric Hamstrings Training on Components of Physical Performance in Young Female Handball Players. *Int J Sports Physiol Perf epub ahead of print,*. 2019.
7. Chaabene H, Prieske O, Negra Y, Granacher U. Change of direction speed: Toward a strength training approach with accentuated eccentric muscle actions. *Sports Med* 48: 1773-1779, 2018.
8. Chaouachi A, Hammami R, Kaabi S, Chamari K, Drinkwater EJ, Behm DG. Olympic weightlifting and plyometric training with children provides similar or greater performance improvements than traditional resistance training. *J Strength Cond Res 28*: 1483-1496, 2014.
9. Daneshjoo A, Rahnama N, Mokhtar AH, Yusof A. Bilateral and unilateral asymmetries of isokinetic strength and flexibility in male young professional soccer players. *J Hum Kinet* 36: 45-53, 2013.
10. de Hoyo M, Sanudo B, Carrasco L, Mateo-Cortes J, DominguezCobo S, Fernandes O, et al. Effects of 10-week eccentric overload training on kinetic parameters during change of direction in football players. *J Sports Sci* 34: 1380–7, 2016.
11. Dos'Santos T, Thomas C, Jones PA, Comfort P. Assessing asymmetries in change of direction speed performance; application of change of direction deficit. *J Strength Cond Res* epub ahead of print, 2018.
12. Douglas J, Pearson S, Ross A, McGuigan M. Eccentric exercise: physiological characteristics and acute responses. *Sports Med* 47: 663-675, 2017.
13. Deurenberg P, Pieters JJ, Hautvast JG. The assessment of the body fat percentage by skinfold thickness measurements in childhood and young adolescence. *Br J Nutr* 63: 293-303, 1990.
14. Elmer SJ, Marshall CS, McGinnis KR, Van Haitsma TA, LaStayo PC. Eccentric arm cycling: physiological characteristics and potential applications with healthy populations. *Eur J Appl Physiol* 113: 2541-2552, 2013.

15. Elmer S, Hahn S, McAllister P, Leong C, Martin J. Improvements in multi-joint leg function following chronic eccentric exercise. *Scand J Med Sci Sports* 22: 653–61, 2012.
16. Faigenbaum AD, McFarland JE, Keiper FB, Tevlin W, Ratamess NA, Kang J, Hoffman, JR. Effects of a short-term plyometric and resistance training program on fitness performance in boys age 12 to 15 years. *J Sports Sci Med* 6: 519, 2007.
17. Falk B, Eliakim A. Resistance training, skeletal muscle and growth. *Pediatr Endocrinol Rev* 1: 120-127, 2003.
18. Garrett JW. Muscle strain injuries: clinical and basic aspects. *Med Sci Sports Exerc* 22: 436-443, 1990.
19. Hammami R, Granacher U, Makhlouf I, Behm DG, Chaouachi A. Sequencing effects of balance and plyometric training on physical performance in youth soccer athletes. *J Strength Cond Res* 30: 3278-3289, 2016.
20. Hammami R, Chaouachi A, Makhlouf I, Granacher U, Behm DG. Associations between balance and muscle strength, power performance in male youth athletes of different maturity status. *Ped Exerc Sci* 28: 521-534, 2016.
21. Hewit JK, Cronin JB, Hume PA. Asymmetry in multi-directional jumping tasks. *Phys Ther Sport* 13: 238-242, 2012.
22. Impellizzeri FM, Rampinini E, Maffiuletti N, Marcora SM. A vertical jump force test for assessing bilateral strength asymmetry in athletes. *Med Sci Sports Exerc* 39: 2044-2050, 2007.
23. Jones P, Bampouras TM, Marrin K. An investigation into the physical determinants of change of direction speed. *J Sports Med Phys Fit* 49: 97–104, 2009.
24. Jones P, Thomas C, Dos'Santos T, McMahon J, Graham-Smith P. The role of eccentric strength in 180 turns in female soccer players. *Sports* 5: 42, 2017.
25. Keiner M, Sander A, Wirth K, Caruso O, Immesberger P, Zawieja M. Strength performance in youth: trainability of adolescents and children in the back and front squats. *J Strength Cond Res* 27: 357-362, 2013.
26. Kovacs MS, Roetert EP, Ellenbecker TS. Efficient deceleration: the forgotten factor in tennis-specific training. *Strength Cond J* 30: 58–69, 2008.
27. Krommes K, Petersen J, Nielsen MB, Aagaard P, Hölmich P, Thorborg K. Sprint and jump performance in elite male soccer players following a 10-week Nordic Hamstring exercise Protocol: a randomised pilot study. *BMC Res Notes* 10: 669, 2017.

28. Meyers RW, Oliver JL, Hughes MG, Cronin JB, Lloyd RS. Maximal sprint speed in boys of increasing maturity. *Ped Exerc Sci* 27: 85-94, 2015.
29. Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones ADG, Cameron N, Brasher. PMA. Enhancing a Somatic Maturity Prediction Model. *Med Sci Sports Exerc* 47: 1755-64, 2015.
30. Morin JB, Gimenez P, Edouard P, Arnal P, Jiménez-Reyes P, Samozino P, Mendiguchia J. Sprint acceleration mechanics: the major role of hamstrings in horizontal force production. *Front Physiol 6*: 404, 2015.
31. Mjølsnes R, Arnason A, Østhagen T, Raastad T, Bahr R. A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. *Scand J Med Sci Sports 14*: 311-317, 2004.
32. Mujika I, Spencer M, Santisteban J, Goiriena JJ, Bishop D. Age-related differences in repeated-sprint ability in highly trained youth football players. *J Sports Sci* 27: 1581-1590, 2009.
33. Naylor J, Greig M. A hierarchical model of factors influencing a battery of agility tests. *J Sports Med Phys Fit 55*: 1329-1335, 2015.
34. Ribeiro-Alvares JB, Marques VB, Vaz MA, Baroni BM. Four weeks of Nordic hamstring exercise reduce muscle injury risk factors in young adults. *J Strength Cond Res* 32: 1254-1262, 2018.
35. Rouissi M, Chtara M, Owen A, Burnett A, Chamari K. Change of direction ability in young elite soccer players: determining factors vary with angle variation. *J Sports Med Phys Fit* 57: 960-968, 2017.
36. Rumpf MC, Cronin JB, Mohamad IN, Mohamad S, Oliver JL, Hughes MG. Kinetic asymmetries during running in male youth. *Phys Ther Sport* 15: 53-57, 2014.
37. Sato K, Heise GD. Influence of weight distribution asymmetry on the biomechanics of a barbell back squat. *J Strength Cond Res* 26: 342-349, 2012.
38. Sheppard JM, Young WB. Agility literature review: classifications, training and testing. *J Sports Sci* 24: 919–32, 2006.
39. Spiteri T, Cochrane JL, Hart NH, Haff GG, Nimphius S. Effect of strength on plant foot kinetics and kinematics during a change of direction task. *Eur J Sport Sci* 13: 646–52. 3, 2013.
40. Sporis G, Jukic I, Milanovic L, Vucetic V. Reliability and factorial validity of agility tests for soccer players. *J Strength Cond Res 24*(3), 679-686, 2010.

41. Tous-Fajardo J, Gonzalo-Skok O, Arjol-Serrano JL, Tesch P. Enhancing change-of-direction speed in soccer players by functional inertial eccentric overload and vibration training. *Int J Sports Physiol Perf* 11: 66-73, 2016.
42. Zafeiridis A, Dalamitros A, Dipla K, Manou V, Galanis N, Kellis S. Recovery during high-intensity intermittent anaerobic exercise in boys, teens, and men. *Med Sci Sports Exerc* 37: 505-512, 2005.

Figure Legends

Figure 1. Schematic of the 4 × 5 meters agility test.

Figure 2. Mean ± SD of 10m sprint time pre-post intervention for intervention (INT) and control (CON) groups.

Figure 3. Mean ± SD of 30m sprint time pre-post intervention for intervention (INT) and control (CON) groups.

Figure 4. Mean ± SD of Agility test performance pre-post intervention for intervention (INT) and control (CON) groups.

Figure 5. Mean ± SD of Standing long jump performance pre-post intervention for intervention (INT) and control (CON) groups.

Figure 6. Mean ± SD of 3 hop test performance pre-post intervention for intervention (INT) and control (CON) groups.

Table 1. Participant Characteristics.

	Mean (SD)
Body Mass (kg)	39.8 (6.0)
Height (cm)	146.2 (6.5)
Sitting Height (cm)	72.3 (4.2)
Leg Length (cm)	73.8 (4.1)
APHV (years)	13.2 (0.4)

Table 2. (EHT) Training program

Exercices		Week 1	Week 2	Week 3	Week 4	Week 5	W
Load	Duration	60% 1RM	70% 1RM	80% 1RM	60% 1RM	70% 1RM	80% 1R
Glute-hamstring raise	3 – 5s	3 × 10	4 × 12	5 × 12	3 × 10	4 × 12	5 ×
anual glut-hamstring rise	3- 5s	3 – 5s	3 × 10	4 × 12	5 × 12	3 × 10	4 ×
ıgle leg romanian dead lift	3 – 5s	3 × 10	4 × 12	5 × 12	3 × 10	4 × 12	5 ×
·idge and hip thrust free weight essed to dumbell and barbell	3 – 5s	3 × 10	4 × 12	5 × 12	3 × 10	4 × 12	5 ×
morning dumbell or barbell	3 – 5s	3 × 10	4 × 12	5 × 12	3 × 10	4 × 12	5 ×

Table 3. Mean ± SD and 95% Cis of dependant variables in intervention (INT) and control (CON) groups pre and post 6-weeks training

	INT				CON			
	Pre		Post		Pre		Post	
	M (SD)	95%CI	M (SD)	95%CI	M (SD)	95%CI	M (SD)	95%CI
1RM (Kg)	35.0 (7.4)	29.6-40.3	46.7 (9.6)	39.8-53.6	33.0 (7.5)	27.6-38.4	42.1 (4.9)	38.5-45.6
SLJ (cm)	169.5 (10.3)	162.1-170.0	178.5 (11.7)	170.1-186.9	171.5 (12.9)	162.3-180.7	167.0 (18.5)	153.7-180.3
3 Hop test (cm)	440 (42.4)	409.6-470.3	467 (43.9)	435.5-498.5	474.0 (49.1)	438.9-509.1	457 (51.0)	420.5-456.7
Single Right Leg Hop test (cm)	159.5 (10.9)	151.7-167.3	164.0 (8.1)	158.2-169.8	153.5 (15.1)	142.7-164.3	156.5 (23.4)	139.8-173.2
Single Left Leg Hop test (cm)	152.5 (15.5)	141.4-163.6	158 (9.5)	151.2-164.8	146 (21.4)	130.6-161.3	148.0 (23.2)	131.4-164.6
Inter-Limb Imbalance (%)	63.9 (10.9)	56.2-71.8	67.6 (9.2)	61.1-74.2	58.8 (11.2)	50.7-66.8	62.1 (23.2)	45.4-78.6
Symmetry Index (%)	105.1 (6.8)	100.1-109.9	103.9 (3.8)	101.2-106.6	106.1 (7.3)	100.7-111.3	106.1 (5.1)	102.5-109.6
Anertior	53.5 (6.7)	48.7-58.3	56.4 (6.0)	52.1-60.7	48.6 (7.3)	44.3-52.9	44.8 (4.6)	41.5-48.2
Posterior-mediale right	58.1 (7.4)	52.7-63.4	59.6 (6.4)	54.9-59.6	62.5 (10.7)	54.8-70.2	62.5 (5.2)	58.8-66.2
Posterior-mediale left	63.1 (8.1)	57.3-68.9	65.5 (6.4)	60.8-70.1	61.9 (5.7)	57.8-66.1	67.2 (4.6)	63.6-70.8
Y-Balance Score	80.8 (2.5)	75.1-86.5	83.8 (6.8)	78.9-88.6	76.8 (8.8)	70.5-83.1	77.3 (4.9)	73.8-80.8
Agility (secs)	7.5 (0.3)	7.3-7.7	7.2 (0.3)	6.9-7.4	7.9 (0.5)	7.5-8.3	7.9 (0.4)	7.6-8.2
10m Speed (secs)	2.1 (.2)	1.9-2.2	1.9 (.1)	1.8-1.9	1.9 (0.1)	1.8-2.1	2.9 (0.2)	1.9-2.2
30m Speed (secs)	5.5 (0.3)	5.3-5.7	5.3 (0.3)	5.0-5.5	5.4 (0.2)	5.3-5.6	5.5 (0.3)	5.3-5.8

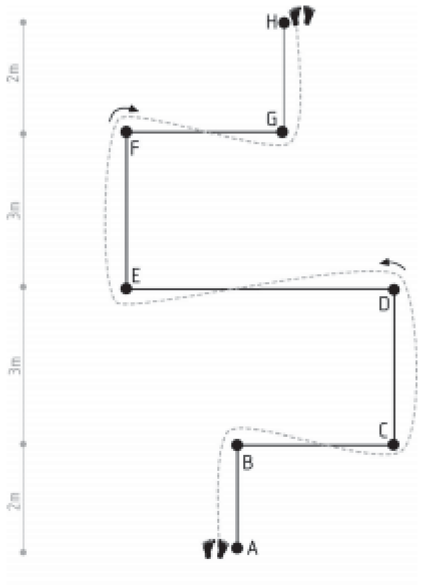
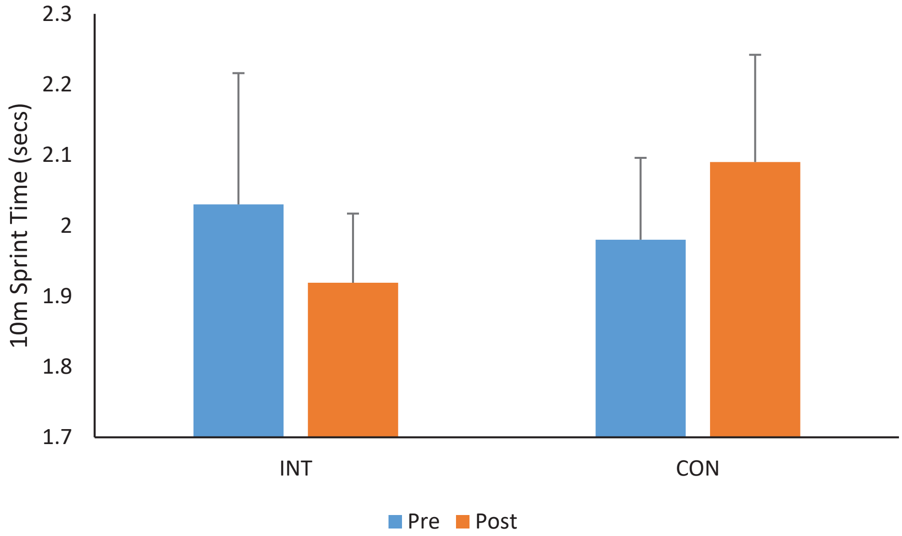


Figure 1.



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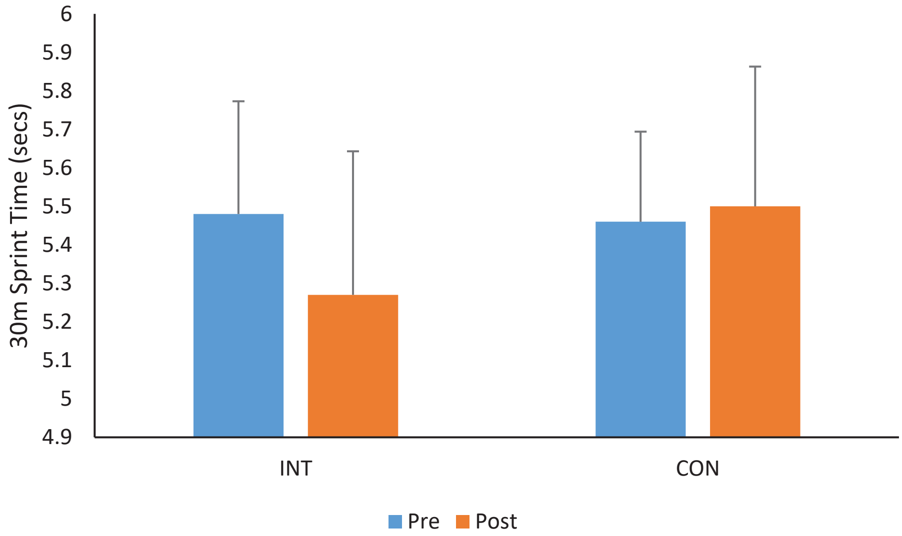
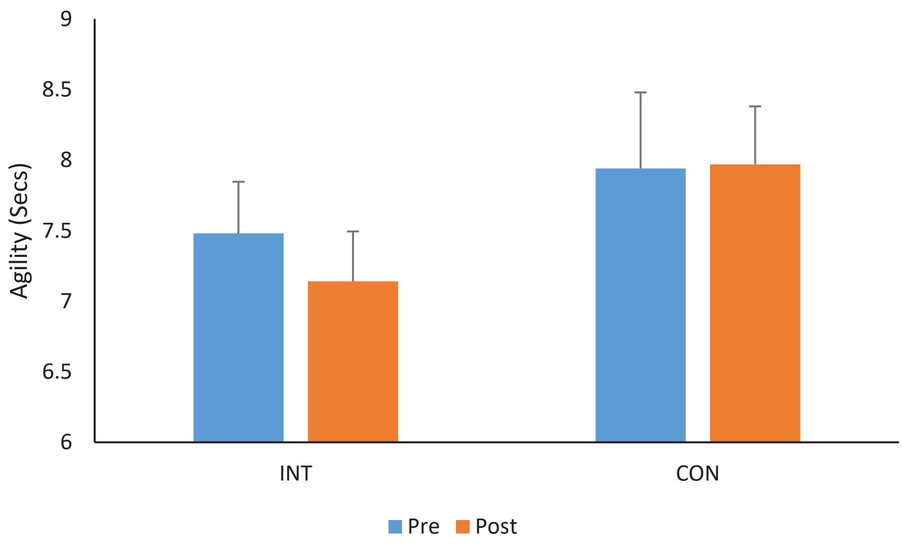

6
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5
4.9
30m Sprint Time (secs)
INT
CON
Pre
Post

Figure 3.



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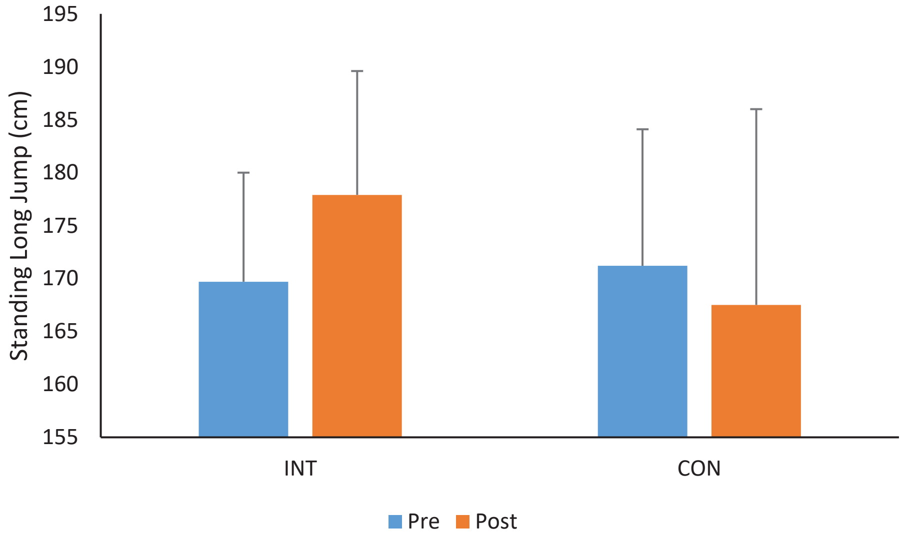
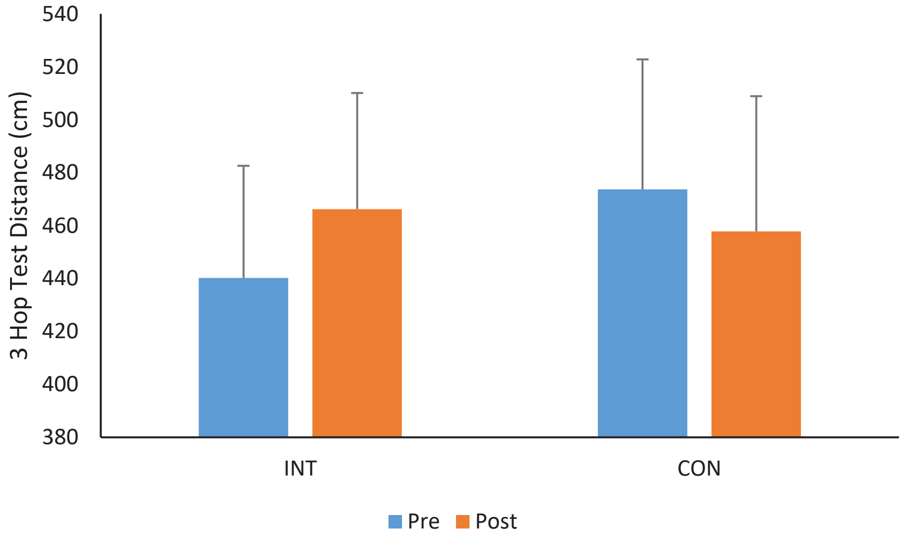


Standing Long Jump (cm)
195
190
185
180
175
170
165
160
155
INT
CON
Pre
Post

Figure 5.



540
520
500
480
460
440
420
400
380
3 Hop Test Distance (cm)
INT
CON
Pre
Post

Figure 6.