EFFECTS OF 8 WEEKS OF ISO-INERTIAL VS. CABLE-RESISTANCE TRAINING ON MOTOR SKILLS PERFORMANCE AND INTER-LIMB ASYMMETRIES

Abstract

The aim of this study was to compare the effects of 8 weeks of iso-inertial vs. cable-resistance training on motor skills performance and inter-limb asymmetries in handball players. Thirty-four young male handball players (mean ± SD: age: 15.96 ± 1.39 years; height: 1.74 ± 0.73 m; body mass: 70.5 ± 13.3 kg) participated in a randomized trial. The players performed an iso-inertial program using a portable flywheel device or a cable-resistance device. Performance variations and inter-limb asymmetries in dominant (D) and non-dominant (ND) limb means of the unilateral countermovement jump (UCMJ), the unilateral lateral jump (ULJ), the unilateral broad jump (UBJ), handball throwing (HT), change of direction speed (COD180), the linear sprint (S20), the V-CUT test and the repeated change of direction (RCOD) were recorded. Significant interactions were shown in $RCOD_D$ ($p = 0.003$, $\eta_p = 0.25$), HT ($p = 0.015$, $\eta_p = 0.17$) and $UCMJ_{ASY}$ ($p = 0.037$, $\eta_p = 0.13$). Post-hoc testing revealed a higher effect sizes in the iso-inertial group ($p < 0.05$) for the performance improvements in $RCOD_D$ (-1.35 large vs -0.22, small) and HT (0.88, moderate vs 0.00, trivial), in addition to inter-limb asymmetry reductions in $UCMJ_{ASY}$ (-0.70 moderate vs -0.32, small). Significant main effects of time in COD180, RCOD, UCMJ and UBJ for both limbs ($p < 0.05$, from moderate to large effect size), and in ULJ_{ND} ($p < 0.001$, large), $UCMJ_{ASY}$ ($p < 0.001$, moderate), V-CUT ($p = 0.014$, small) and HT ($p = 0.015$, large) were found. The effect sizes revealed greater magnitudes in the iso-inertial group. In conclusion, although both resistance training programs improve players' to physical performance and reduce inter-limb asymmetries, greater improvements were recorded with the iso-inertial resistance training than with the cable-resistance methodology.

Key Words: Change of direction; jump; handball; young athletes.

INTRODUCTION

Handball is a high-intensity intermittent sport (19) characterized by repeated explosive actions such as jumping, change of direction (COD), accelerations, decelerations and ball throwing (28,37,45). The total distance covered in competitive matches has been shown to be 3.231 m (30), with intensity variation occurring every 3.2 s (30). Averages of maximum speed (22 km·h^{-1}) (1), accelerations (2.26 acc·min^{-1}), decelerations (3.61 dec·min^{-1}) and frequency of change of direction (7.88 COD·min^{-1}) have also been described (23). Given the prevalence of COD actions in handball, it is unsurprising that this motor skills is considered to be of great relevance for the sport (30,37). The study of COD has previously focused on analyzing its association with eccentric muscle actions (6,7,22), braking strategies (34), the ability to change direction at different angles (9), and the capacity to perform COD actions repeatedly (6,33). However, information about the effects of resistance training programs on COD performance in handball athletes is scarce. In recent years, iso-inertial strength training has become a popular training method for developing strength to enhance sport-specific skills (14,24,36,43). Tesch et al. (42) suggested that one of the advantages of iso-inertial training is the increased effort required during both the concentric and eccentric phases of the exercise. Recently, Nuñez et al. (36) compared the effects of a 6-week unilateral lunge or bilateral squat iso-inertial program in team-sports players, showing how both methods improve the countermovement jump (CMJ) (d = 0.28-0.42) and COD speed performance in $COD90_D$ (d = 0.75-0.70). Similarly, Gonzalo-Skok et al. (14) used iso-inertial training to compare the effects of bilateral squats vs. multidirectional COD exercises in team-sports players, showing likely or very likely improvements showing likely or very likely improvements in COD skills (e.g., COD 10m (d = 0.61 - 0.54) or COD 20m (d = 0.35 - 0.43)), and in jumping tests (e.g., bilateral and unilateral CMJ (d = 0.27 to 0.42), lateral jump (ULJ) (d

= 0.51 - 0.87) and broad jump (UBJ) (*d* = 0.43 - 0.62)). When considering the application of iso-inertial training, various authors have indicated that factors such as force vector application, variability and specificity to sporting movements are key aspects in optimizing transfer to sport (14,32,43).

However, traditional resistance training is still the most widespread strength training methodology, and has been designed with different levels of functionality, ranging from resistance machines and free weights to functional loading on cable machines (38,40). Many studies have shown the beneficial effects of traditional resistance training on jump (8,17,41), COD and speed performance (17,41). Hermassi et al. (17) used a combination of weightlifting and strength exercises (e.g., pull-over, snatches, bench press, clean and jerk) for 12 weeks in male handball players. The results showed the greatest improvements in CMJ (*d* = 2.59), squat jump (*d* = 1.54) and throwing velocity (*d* = 1.33 to 2.13). Additionally, in a 6-week weightlifting (hang power clean, power snatch, half squat) and vertical jump intervention, Teo et al. (41) showed the greatest improvements in CMJ (*d* = 0.70 - 0.34), squat jump (*d* = 0.85 - 0.39) and COD505 (*d* = 0.48 - 0.44) performance tests. While the benefits of strength and power training are irrefutable, the literature comparing free weight training and iso-inertial methods are scarce, and only two reviews have been published (27,44) with no definitive results in favor of either methodology.

In addition to performance, neuromuscular inter-limb asymmetries have frequently been studied to quantify performance differences between limbs (4,10,25). For example, Bishop et al. (4) showed that larger inter-limb asymmetries in the drop jump test (9.16%) are associated with slower performance during the COD505 test (*r* = 0.52 - 0.66) and 30m speed (*r* = 0.58) tests in adult female soccer players. Furthermore, Maloney et al. (26) recorded an association between drop jump asymmetries and slower COD90º times (*r* =

0.60) in healthy males. Madruga-Parera et al. (24) also related higher inter-limb asymmetries in the double COD test to decreased performance in UCMJ (r = 0.50 - 0.53) and COD actions (r = 0.50 - 0.63) in young elite tennis players. Despite these moderate associations, it is plausible to limit the possible cause and effect relationship of the aforementioned results.

Therefore, the aim of the current study was to evaluate the effects of 8 weeks of a resistance training program based on COD exercises using either iso-inertial resistance or cable-resistance training devices, on motor skills performance and inter-limb asymmetries. The authors hypothesized that both training types could be effective to improve motor skills values in handball players, although iso-inertial training would be more effective than cable-resistance training.

METHODS

Experimental approach to the problem

This research used a randomized trial to determine the effect of strength training on motor skills variables in young handball players. Peak height velocity (PHV) was calculated following the formula proposed by Mirwald et al. (31), where early maturing (pre-PHV) is defined as preceding the average age of PHV by 1 year, average maturing (circa-PHV) refers to ± 1 year from PHV, and late maturing means > 1 year after PHV (post-PHV). All the athletes were previously familiarized with the testing procedures. The tests included bilateral and unilateral jumps, COD sprints over several distances, linear sprint and a throwing handball test. Furthermore, asymmetries were calculated in all the unilateral tests. Testing sessions were separated by a 48-hour recovery period (Figure 1). The evaluators were blinded and the players were asked not to perform any strenuous exercise the day before each test, to consume their last meal at least 3 hours before the scheduled tests, and to avoid caffeine supplements for at least 24 hours before the tests.

** PLEASE INSERT FIGURE 1 ABOUT HERE **

Subjects

Thirty-four young male handball players (mean ± SD: age: 15.96 ± 1.39 years; post-peak high velocity: 1.42 ± 1.39; height: 1.74 ± 0.73 m; body mass: 70.5 ± 13.3 kg) volunteered to participate in this study. Data collection took place during the competitive season after a 2-month pre-season period. All the players were actively involved in a high-level young handball league, doing three training sessions (approximately 4.5 hours) and playing a competitive match per week. Subjects were eligible for inclusion if they had > 4 years of competitive handball experience and were excluded if they presented an injury (overuse or acute) at the time of testing. Before taking part in the study, participants and their parents/guardians were fully informed about the protocol and provided their written informed consent. The Catalan Sports Council Ethics Committee approved the procedures in accordance with the latest version of the Declaration of Helsinki.

Procedures

The tests were performed in two different sessions. Jumping and throwing tests were administered on the first day, while linear sprint and COD tests were carried out on the second day. A standardized warm-up was performed prior to the tests, consisting of five minutes of light jogging, three minutes of dynamic stretches and five minutes of lower body strength work such as multi-directional lunges, inchworms, bodyweight squats and planks. Upon completion, three practice trials were provided for each test where subjects were instructed to perform them at 75, 90 and 100% of their perceived maximal effort. Three minutes rest was given between the last practice trial and the start of the tests, which were administered in a randomized order.

Day 1. Unilateral countermovement jump (UCMJ). This test was performed on a contact mat (Chronojump, Boscosystem, Barcelona Spain), and jump height was measured. Subjects were required to step onto the center of the contact mat with one leg and place their hands on their hips. When ready, they performed a countermovement to a self-selected depth before accelerating as forcefully as possible into a unilateral vertical jump, following the instructions to 'jump as high as you can'. The non-jumping leg was slightly flexed at the knee with the foot hovering next to the ankle of the jumping leg. No additional swinging of the non-jumping leg was allowed during the jump and hands were required to remain fixed at the hips. Any deviations from these criteria resulted in a void trial and the test was subsequently retaken. Three trials were performed on each leg with 60 seconds rest given between each trial. The highest jump on each leg was then used for subsequent data analysis (12,24,29).

Unilateral lateral jump (ULJ). This test was performed to measure lateral jump distance using a standard measuring tape fixed to the floor. The subjects started just behind 0 cm with the selected test leg, performing a countermovement to a self-selected depth before jumping laterally as far as possible in the direction of the tape measure (without landing directly on it), with hands placed and held on the hips throughout. Considering the difficulty of this test, the landing was performed on both limbs to increase the chance of a stable landing. The subjects were required to maintain the landing position for 2 seconds. The jumping distance was measured from the heel of the jumping foot. Three trials were performed on each leg with 60 seconds rest given between each trial. The trial with the furthest jump on each leg was then used for subsequent data analysis (12,24,29).

Unilateral broad jump (UBJ). This test was performed to measure horizontal jump distance (in cm) using a standard measuring tape fixed to the floor. The subjects started with their toes just behind 0 cm with the selected test leg, performing a countermovement to a self-selected depth before jumping forward as far as possible along the direction of the tape measure (without landing directly on it), with hands placed on the hips throughout. The subjects were required to maintain the landing position for 2 seconds. The jumping distance was measured from the heel of the jumping foot. The non-jumping leg was slightly flexed at the knee with the foot hovering next to the ankle of the jumping leg. No additional swinging of the non-jumping leg was allowed during the jump. Any deviations from these criteria resulted in a void trial and the test was subsequently retaken. Three trials were performed on each leg with 60 seconds rest given between each trial. The furthest jump on each leg was then used for data analysis (12,24,29).

Handball Throwing test (HT). Subjects were required to stand on a throwing point 7 m from the goal (penalty line). The procedure proposed by Saeterbakken et al. (39) was to perform a maximum throwing action with the ball (mass 480 g and circumference 58 cm). The ball velocity was determined by using speed radar (16-177 $km \cdot h^{-1}$; 27 m; Bushnell Speedster II; USA). The radar was placed behind the goal. Three trials were performed with 120 seconds rest given between each trial. The quickest throw was then used for subsequent data analysis.

Change of Direction 180º Speed test (COD180). Subjects performed two 180º changes of direction using the same leg in each trial for both the dominant (COD180_D) and the non-dominant (COD180_ND) legs (24). The first change of direction was performed 7.5 m after the start, and the second one was performed 5 m after the first change of direction. The subjects sprinted for a distance of 20 m. Total time in the COD test was measured using photocells, placed at a height of 0.75 m (in all the speed tests). The fastest time of the three trials for each leg was used for the analysis. A trial was considered successful if the entire foot crossed over the line while changing direction. Each trial was separated by a 180-second recovery period. An adapted calculation was used to evaluate the COD deficit, as described by Nimphius et al. (35). Thus, the COD deficit was calculated as follows: S20 velocity-COD test velocity.

Linear sprint 20 m (S20). Time in the sprint test was measured using photocells, placed on the starting line and after 20 m. The photocells were connected to a laptop and analyzed using a software (Chronojump, BoscoSystem, Barcelona, Spain). The front foot was placed 0.5 m in front of the first photocell beams. The fastest time of the three trials was used for the analysis. Each trial was separated by a 180-second recovery period.

V-CUT test. Subjects performed a 25 m circuit at maximum speed, with four 45° COD actions, each one after a distance of 5 m (13). To achieve a valid trial, the subjects had to pass the line clearly marked on the floor with each respective foot at every turn. The distance between each pair of cones was 0.7 m. The photocells were connected to a laptop and analyzed using a software (Chronojump, BoscoSystem, Barcelona, Spain). Three trials were performed with 180 seconds rest provided between each and the fastest trial was subsequently used for further analysis.

Repeated change of direction (RCOD) 8 x 10 m. This test is related to the athlete's capacity to resist fatigue during a change of direction task. The test involved eight continuous repetitions of a 10 m sprint, with each 10 m sprint requiring a 180º change of direction at the halfway point (5 m). The photocells were connected to Chronojump software to acquire the data (Chronojump BoscoSystem, Barcelona, Spain). For the purpose of observing the association between inter-limb asymmetries and performance when athletes are in an acute state of 'fatigue', we modified this previously validated CODS test (5) by carrying out 8 consecutive sprints (no rest between any of them), instead of a single maximal effort. Owing to the fact this test acutely induces fatigue it was only performed twice, ensuring each time that all the turns were conducted off the same limb. A rest period of 5 minutes between trials was provided, with the outcome of total time for all 8 sprints combined and used for further analysis.

Training intervention

Players from the same handball club were assigned to either an iso-inertial (n = 17) or a cable (n = 17) resistance training program. A portable iso-inertial device (Byomedic System^{SCP}, Barcelona, Spain) (32) was used in the iso-inertial program. The cable-resistance group used a cable-resistance machine (Salter Sport SA, Functional trainer Inspire FT1, Barcelona, Spain) (Figure 2).

** PLEASE INSERT FIGURE 2 ABOUT HERE **

The resistance training program lasted 8 weeks (Table 1) and consisted in two weekly sessions that including COD ability, perception constraints and specific handball skills (Figure 3). The progression of this program was focused on the introduction of new skills and specific constraints every two weeks (more steps to develop the actions, increased planes of motion and the introduction of a number of specific skills). The load (inertia and weight) was adapted to the subjects in each session using the Scale of Rate of Perceived Effort (RPE), as suggested in previous studies (16). The players were encouraged to perform the different exercises at maximum effort. Two qualified strength and conditioning coaches controlled each training session, providing the subjects with verbal encouragement and specific coordinative feedback (e.g. “keep down the center of gravity”, “stabilize the core and lower limbs at the braking stage”, “accelerate as fast as you can”).

This strength program was added to the subjects’ regular handball training (three 90-minutes sessions per week on Monday, Wednesday and Friday) and a competitive match over the weekend. The handball training included technical and tactical skills and excluded any other strength program.

** PLEASE INSERT TABLE 1 & FIGURE 3 ABOUT HERE **

Statistical Analyses

The data are presented in mean ± standard deviation (SD). The assumption of normality was verified using the Shapiro-Wilk test and the Q-Q plots and histogram of residuals were explored. An intra-day reliability test was performed and interpreted in line with Koo and Li (20), where values > 0.9 = *excellent*, 0.75 - 0.9 = *good*, 0.5 - 0.75 = *moderate* and < 0.5 = poor. The effectiveness of the interventions was assessed by a 2-way mixed ANOVA. Group intervention ("ISO", "Cable") was included as a between-subject factor; time ("Pre", "Post") was included as the repeated within-subject factor; and group x time was included to account for the interaction effects. Whenever a significant mean effect or interaction was observed, Bonferroni's post hoc correction was used to aid interpretation of these interactions. Within-subject Cohen's effect size was calculated using the formula $d = t/\sqrt{(n)}$ (21) and was interpreted as < 0.2 = *trivial*; 0.2-0.6 = *small*; 0.6-1.2 = *moderate*; 1.2-2.0 = *large*; > 2.0 = *very large* (18). Researchers were blind to all subjects during the analyses. The significance level was set at α = 0.05 for all the tests. All the statistical analyses were performed in JASP (version 0.11.1; JASP Team, 2019, University of Amsterdam, the Netherlands).

Inter-limb asymmetries were calculated for all tasks, defining the dominant (D) (the limb with the better score) and the non-dominant (ND) limbs. The mean inter-limb asymmetries were computed using a standard percentage difference equation: 100/(max value)*(min value)*-1*100, which is an accurate equation for the quantification of asymmetries in unilateral tests (3).

RESULTS

Participants

Only players who participated in at least 80% of the training sessions were analyzed. Consequently, 6 of the forty players were excluded for various reasons. None of the players were injured during the resistance training sessions. As a result, 34 players (mean ± SD: age: 15.96 ± 1.39 years; post-peak high velocity: 1.42 ± 1.39; height: 1.74 ± 0.73 m; body mass: 70.5 ± 13.3 kg) were included in the final analyses. Furthermore, for 28 out of the 34 players their preferred leg (i.e., kicking leg) was the right leg, and 31 right of the 34 players preferred the right arm (i.e., throwing arm). The final sample sizes for the training groups were 17 for the iso-inertial group and 17 for the cable-resistance group.

Tests' reliability

Intra-day reliability in pre- and post-intervention tests was *good* to *excellent* (Table 2).

Effectiveness of intervention groups

The summary of the results for change of direction and linear sprint are shown in Table 3.

** PLEASE INSERT TABLE 2 & 3 ABOUT HERE **

180º Change of Direction Speed test

The data revealed a significant main effect of time ($p < 0.001$) in changes of direction performed with both the dominant (d = -0.83, moderate) and the non-dominant legs (d = -0.71, moderate). However, non-significant interactions were shown in both legs (D: $p > 0.05$, $\eta_p = 0.00$; ND: $p > 0.05$, $\eta_p = 0.00$), indicating a similar improvement in both groups. A non-significant main effect of time and interaction were observed in the asymmetry index (time: $p = 0.570$, $d = 0.10$, trivial; group*time: $p = 0.480$, $\eta_p = 0.02$) in change of direction and in change of direction deficit (time: $p = 0.356$, $d = 0.10$, trivial; group*time: $p = 0.314$, $\eta_p = 0.01$).

V-CUT test

The data revealed a significant main effect of time ($p = 0.014$, $d = -0.43$, small) and a non-significant interaction ($p = 0.092$, $\eta_p = 0.09$) in the V-Cut test, indicating that a similar improvement occurred in both groups.

Repeated change of direction 8 x 10 m

The data revealed a significant main effect of time ($p < 0.001$) in repeated changes of direction performed with both the dominant ($d = -0.69$, moderate) and the non-dominant legs ($d = -0.71$, moderate), while a non-significant main effect of time was observed in the asymmetry index ($p = 0.303$, $d = -0.19$, trivial). Significant interactions were shown in repeated changes of direction performed with the dominant leg ($p = 0.003$, $\eta_p = 0.25$) only. The post-hoc test showed a significant difference between "Pre" (15.96 ± 2.00) and "Post" (12.59 ± 1.50) in the iso-inertial group ($p_{Bonferroni} \leq 0.05$, $d = -1.35$, large), indicating that an improvement occurred in this group only.

Linear sprint 20 m (S20)

The data revealed a non-significant main effect of time ($p = 0.866$, $d = -0.03$, trivial) and interaction ($p = 0.119$, $\eta_p = 0.07$) in the 20 m-sprint time.

The summary of the results in the jump and handball throwing tests are shown in Table 4.

** PLEASE INSERT TABLE 4 ABOUT HERE **

Unilateral countermovement jumps

The data revealed a significant main effect of time ($p < 0.001$) in jumps performed with both the dominant ($d = 0.93$, moderate) and the non-dominant legs ($d = 1.06$, moderate) and in the asymmetry index ($d = -0.66$, moderate). Significant interaction was revealed in the asymmetry index ($p = 0.037$, $\eta_p = 0.13$). The post-hoc test showed a significant difference between "Pre" (14.81 ± 8.82) and "Post" (6.05 ± 2.93) in the iso-inertial group ($p_{Bonferroni} \leq 0.05$, $d = -0.70$, moderate), indicating that an improvement occurred in this group only.

Unilateral lateral jumps

The data only revealed a significant main effect of time in the unilateral lateral jumps performed with the non-dominant leg ($p = 0.022$, $d = 0.42$, small).

Unilateral broad jump

The data revealed a significant main effect of time ($p < 0.001$) in the unilateral broad jumps performed with both the dominant ($d = 1.37$, large) and the non-dominant leg ($d = 1.20$, large), while the main effect in the asymmetry index was not significant ($p = 0.427$, $d = -0.12$, trivial). Non-significant interactions were revealed in both the dominant ($p = 0.126$, $\eta_p = 0.07$) and the non-dominant ($p = 0.876$, $\eta_p = 0.00$) unilateral broad jumps and in the asymmetry index (($p = 0.121$, $\eta_p = 0.07$)), indicating a similar evolution in the two groups.

Handball throwing test

The data revealed a significant main effect of time (p = 0.015, d = 0.41) and interaction (p = 0.015, η_p = 0.17) in the handball throwing test. The post-hoc test showed a significant difference between “Pre” (70.76 ± 1.18) and “Post” (72.94 ± 7.33) in the iso-inertial group ($p_{Bonferroni} \leq 0.05$, d = 0.88, moderate), indicating that an improvement occurred in this group only.

DISCUSSION

The aim of the current study was to evaluate the effects of an 8-week resistance-training program based on COD exercises using either iso-inertial or cable-resistance devices. Motor skills performance and inter-limb asymmetries were recorded in a wide range of tests such as COD, sprinting, jumping and throwing actions. Both resistance training programs showed improvements in the motor skills variables. When comparing groups, significant results were found in favor of the iso-inertial training in $RCOD_{DL}$ and HT performance, as well as for UCMJ inter-limb asymmetries. Furthermore, the iso-inertial resistance group showed greater non-significant training effects in COD180, $RCOD_{ND}$, V-CUT, UCMJ, ULJ and UBJ. Meanwhile, the cable-resistance group showed greater non-significant training effects in COD180, $RCOD_{ND}$ and UBJ_{ND}.

Given the importance of COD actions in handball (30,37), we developed three COD tests with different specifications: COD180, V-CUT and RCOD. The COD180 showed positive effects in both training methods, with superior improvements on comparing with previous data with team sport players (*d* = -0.28 and -0.61 for D and ND, respectively) (14). Considering the improvement in both groups, highlighting the design of our intervention over the applied resistance kind makes sense. Regarding the V-CUT test, moderate effects were obtained only in the iso-inertial group, being in agreement with Tous-Fajardo et al. (43), who registered better times in the V-CUT test after an iso-inertial resistance training program with multidirectional COD in young soccer players. It is important to emphasize these results, taking the multidirectional nature of this test and its relationship with the demands of the change of direction in handball into account. It is plausible to think that the nature of the iso-inertial resistance intervention, which is focused on the concentric and eccentric actions (11) and accentuates the required effort of the breaking phases (42), could bring about these adaptations. These events could explain the aforementioned adaptations. Concerning the $RCOD_{D}$ test, significant improvements were reported in the iso-inertial group, while moderate effects were found in $RCOD_{ND}$ in both groups. Such improvements agree with Tous-Fajardo et al. (43), who analyzed the effects on repeated sprint ability with young football players following an iso-inertial training. Considering these results, it is important to highlight the great adaptation to repetitive stimulus showed by both training groups, although superior results were again found after the iso-inertial training. In contrast to the positive results showed in COD actions, no favorable within-group and between-group effects were shown in the 20 m sprint test, with similar results to Tous-Fajardo et al. (43) in the 10 m and 30 m sprint distances, confirming the lack of transfer from our COD-task intervention to linear skills.

Regarding asymmetries, the present research did not show any effect in the COD tests. Given that the available literature is not reporting a cause and effect relationship between performance improvement and reduction of inter-limb asymmetries, the positive effects of the present intervention on performance without achieving any decrease of COD asymmetries can be accepted.

In jumping tests, greater effects were found in UCMJ, ULJ_{ND} and UBJ for the iso-inertial group, while only UBJ showed improvements in the cable-resistance group. This is a significant finding since jump capacity is an important specific skill in handball (15). The improvement in jumping capability after an iso-inertial resistance training program has been previously shown by Gonzalo-Skok et al. (14) in UCMJ (d = 0.27 and 0.39, for D and ND, respectively) and the single-hop test (d = 0.43 and 0.62, for D and ND, respectively). The positive effects on jumping performance after iso-inertial training is an interesting point to consider, especially given that this intervention program was non-focused on this motor skills but nonetheless reported a transfer effect.

Related to jumping asymmetries, between-group differences in favor of the iso-inertial training group were limited to UCMJ, while non-differences were reported in ULJ and UBJ. Our results contrast with the previous literature, which has showed asymmetry reductions in single and triple hop tests (12) with iso-inertial resistance training. These divergent data related to the direction of jumping action undergoing a decrease in asymmetry suggest the need to increase the number of experimental designs to determine a more consistent adaptation in jumping asymmetry after iso-inertial strength training. Nevertheless, with respect to the asymmetry reduction in UCJMJ, the present program, which included a wide range of unilateral coordinative tasks, gave a positive adaptation since high scores in vertical jumping asymmetries were related to a decrease in sprint and COD performance (2,24).

To complete the performance screening of the present study, a handball throwing speed test was performed, reporting differences between groups in favor of iso-inertial training. Previous studies have related the transfer of forces from core muscles to the upper limbs and throwing performance after traditional abdominal training (39) and upper limb weightlifting exercises (17). Considering these studies and the continued presence of trunk rotational movements through the present strength program, it is plausible to understand the throwing speed gain by means of the existence of a kinetic chain working from the lower to the upper limbs, especially when there is a high demanding eccentric overload produced by the iso-inertial devices.

There are two methodological considerations related to the present study. First, despite being focused on sport specific skills, the developed program is still removed from the competitive environment, so the adaptations are related to the effects of motor skills tests but not to sport performance. Second, and related to the actions carried out by the volunteers throughout the initial phase of the present study, when working with iso-inertial resistance, which is still little used by athletes, more thorough familiarization with this type of training is recommended before starting an experimental intervention.

Practical Applications

This study supports the introduction of the iso-inertial methodology when applying strength resistance training in order to improve motor skills performance. Practitioners can thereby introduce a strength program based on motor skills and perceptual constraints, increasing the coordinative difficulty without limiting any positive adaptations and facilitating the reduction of inter-limb asymmetries.

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Table 1. Programme training, exercises, stimuli and load following iso-inertial and cable resistance groups

Stage	Week	Exercise	Purpose of exercise	Load sets & reps	RPE
1	1-2	Forward lunge	Ball in the hands	3x12	6-7
	1-2	Acceleration	1 step – ball in the hands	3x12	6-7
	1-2	Lateral squat	Ball in the hands	3x12	6-7
2	3-4	Single leg hop	Simulating passes	3x12	7-8
	3-4	Acceleration	2 steps – simulating passes	3x12	7-8
	3-4	Lateral lunge	Simulating passes	3x12	7-8
3	5-6	Crossover step	Simulating passes	3x8	8-9
	5-6	Acceleration	2 steps – pass and receive	3x8	8-9
	5-6	Lateral step & UCMJ	Simulating passes	3x8	8-9
4	7-8	Crossover step	Pass and receive	3x8	8-9
	7-8	Acceleration	2 steps – defense action	3x8	8-9
	7-8	180º turn	Pass and receive	3x8	8-9

Reps: repetitions; RPE: scale rated of perceived effort; UCMJ: unilateral countermovement jump

Table 2. Intra-day intraclass correlation coefficient reliability, following baseline tests.

PRE-TEST RELIABILITY (n = 34)				
Test	**TRIAL 1**	**TRIAL 2**	**CV (%)**	**ICC (95% CI)**
$COD180_R$ (s)	5.41 ± 0.55	5.36 ± 0.54	1.8	0.97 (0.95 to 0.98)
$COD180_L$ (s)	5.44± 0.55	5.40 ± 0.57	2.1	0.97 (0.94 to 0.98)
V-CUT (s)	7.36 ± 0.67	7.29 ± 0.64	1.5	0.97 (0.95 to 0.98)
$RCOD_R$ (s)	15.82 ± 2.20	15.86 ± 2.11	1.3	0.94 (0.92 to 0.96)
$RCOD_L$ (s)	15.72 ± 2.01	15.26 ± 2.01	2.1	0.95 (0.90, 0.97)
S20 (s)	3.20 ± 0.29	3.18 ± 0.32	1.3	0.98 (0.97 to 0.99)
$UCMJ_R$ (cm)	13.73 ± 3.63	13.73 ± 3.64	6.7	0.95 (0.90 to 0.97)
$UCMJ_L$ (cm)	13.12 ± 3.66	12.82 ± 3.51	8.5	0.91 (0.83 to 0.96)
ULJ_R (cm)	122.93 ± 23.14	124.35 ± 23.83	5.8	0.92 (0.84 to 0.96)
ULJ_L (cm)	128.94 ± 20.80	133.43 ± 20.32	4.1	0.95 (0.91 to 0.97)
UBJ_R (cm)	121.81 ± 21.57	126.78 ± 21.48	5.6	0.91 (0.82 to 0.95)
UBJ_L (cm)	121.79 ± 22.08	127.20 ± 26.45	5.4	0.94 (0.88 to 0.97)
HT ($km \cdot h^{-1}$)	66.50 ± 6.17	68.32 ± 6.49	3.3	0.93 (0.86 to 0.98)

Data are means ± SD; CV = coefficient of variation; ICC = intraclass correlation coefficient; CI = confidence intervals; cm: centimeters; s: seconds; R: right leg; L: left leg; COD: change of direction speed; V-Cut: multidirectional change of direction; RCOD: repeated change of direction 10x8; S20: 20 meters linear sprint test; UCMJ: unilateral countermovement jump; ULJ: unilateral lateral jump; UBJ: unilateral broad jump; HT: handball throwing test.

Table 3. Summary of study results

Iso-inertial vs. cable-resistance training

Table 3. Summary of study results

Outcome	**Group**	**Pre**	**Post**	**Cohen's *d***	***p* (Time)**	***p* (Group)**	***p* (Time*group)**
$COD180_D$ (s)	All	5.26 ± 0.53	5.08 ± 0.42	-0.83	<0.001	0.644	0.931
	Iso-inertial	5.22 ± 0.36	5.04 ± 0.36	-0.83			
	Cable resistance	5.30 ± 0.58	5.12 ± 0.48	-0.80			
$COD180_{ND}$ (s)	All	5.39 ± 0.54	5.23 ± 0.48	-0.71	<0.001	0.528	0.744
	Iso-inertial	5.33 ± 0.50	5.18 ± 0.43	-0.65			
	Cable resistance	5.45 ± 0.59	5.28 ± 0.54	-0.76			
$COD180_{ASY}$ (%)	All	2.42 ± 2.04	2.66 ± 1.88	0.10	0.570	0.251	0.480
	Iso-inertial	1.96 ± 1.81	2.51 ± 1.56	0.16			
	Cable resistance	2.88 ± 2.21	2.82 ± 2.19	-0.02			
$CODD180_{ASY}$ (%)	All	5.77 ± 4.81	6.77 ± 4.84	0.10	0.356	0.262	0.314
	Iso-inertial	4.75 ± 4.31	6.34 ± 4.05	0.22			
	Cable resistance	6.80 ± 5.19	7.19 ± 5.61	-0.02			
V-CUT (s)	All	7.25 ± 0.65	7.15 ± 0.61	-0.43	0.014	0.688	0.092
	Iso-inertial	7.24 ± 0.62	7.07 ± 0.54	-0.74			
	Cable resistance	7.26 ± 0.70	7.23 ± 0.68	-0.15			
$RCOD_D$ (s)	All	15.26 ± 2.02	13.31 ± 2.51	-0.69	<0.001	0.968	0.002
	Iso-inertial	15.96 ± 2.00	12.59 ± 1.50*	-1.35			
	Cable resistance	14.57 ± 1.84	14.02 ± 3.11	-0.22			
$RCOD_{ND}$ (s)	All	16.28 ± 2.08	14.00 ± 2.68	-0.71	<0.001	0.528	0.744
	Iso-inertial	16.87 ± 2.25	13.11 ± 1.73	-0.65			
	Cable resistance	15.69 ± 1.77	14.89 ± 3.20	-0.76			
$RCOD_{ASY}$ (%)	All	6.08 ± 6.25	4.88 ± 2.74	-0.19	0.303	0.103	0.948
	Iso-inertial	5.13 ± 5.77	3.86 ± 2.64	-0.17			
	Cable resistance	7.03 ± 6.73	5.91 ± 2.50	-0.14			
S20 (s)	All	3.16 ± 0.30	3.16 ± 0.33	-0.03	0.866	0.740	0.119
	Iso-inertial	3.16 ± 0.32	3.12 ± 0.30	-0.30			
	Cable resistance	3.16 ± 0.29	3.19 ± 0.37	0.24			

Data are presented as mean ± SD. D: dominant leg; ND: non-dominant leg; cm: centimeters; s: seconds; ASY: inter-limb asymmetries; COD180: 180° change of direction; V-CUT: multidirectional change of direction test; RCOD: repeated change of direction 8x10; S20: linear sprint 20 m.

Significant Cohen's *d* and *p*-values ($p \leq 0.05$) are shown in bold.

* $p_{Bonferroni} \leq 0.05$ different to baseline values.

Table 4. Summary of study results

Outcome	Group	Pre	Post	Cohen's *d*	*p* (Time)	*p* (Group)	*p* (Time*group)
$UCMJ_D$ (cm)	All	15.34 ± 3.65	18.20 ± 3.67	0.93	<0.001	0.248	0.272
	Iso-inertial	15.71 ± 4.19	19.15 ± 3.72	1.12			
	Cable resistance	14.97 ± 3.09	17.24 ± 3.45	0.74			
$UCMJ_{ND}$ (cm)	All	13.48 ± 3.36	17.00 ± 3.40	1.06	<0.001	0.386	0.072
	Iso-inertial	13.41 ± 3.77	17.96 ± 3.40	1.41			
	Cable resistance	13.55 ± 3.77	16.05 ± 3.22	0.78			
$UCMJ_{ASY}$ (%)	All	12.12 ± 8.58	6.42 ± 3.36	-0.66	<0.001	0.172	0.037
	Iso-inertial	14.81 ± 8.82	6.05 ± 2.93*	-0.70			
	Cable resistance	9.44 ± 7.66	6.79 ± 3.80	-0.32			
ULJ_D (cm)	All	139.17 ± 19.58	143.34 ± 19.33	0.30	0.096	0.164	0.764
	Iso-inertial	143.91 ±18.59	147.34 ± 21.43	0.24			
	Cable resistance	134.44 ± 19.53	139.35 ± 16.67	0.35			
ULJ_{ND} (cm)	All	128.42 ± 21.84	133.95 ± 20.06	0.42	0.022	0.133	0.669
	Iso-inertial	133.60 ± 20.63	139.60 ± 20.52	0.49			
	Cable resistance	123.77 ± 22.64	128.31 ± 18.47	0.34			
ULJ_{ASY} (%)	All	7.86 ± 7.94	6.71 ± 4.80	-0.18	0.315	0.374	0.330
	Iso-inertial	7.55 ± 7.38	5.27 ± 3.53	-0.34			
	Cable resistance	8.18 ± 8.69	8.15 ± 5.53	-0.00			
UBJ_D (cm)	All	138.48 ± 23.22	155.93 ± 21.48	1.37	<0.001	0.746	0.126
	Iso-inertial	138.02. ± 23.51	158.82 ± 24.07	1.67			
	Cable resistance	138.94 ± 23.63	153.04 ± 18.82	1.13			
UBJ_{ND} (cm)	All	128.68 ± 21.37	146.21 ± 20.06	1.20	<0.001	0.783	0.876
	Iso-inertial	129.81 ± 24.07	146.94 ± 20.70	1.15			
	Cable resistance	127.54 ± 19.87	145.47 ± 20.00	1.21			
UBJ_{ASY} (%)	All	6.97 ± 4.71	6.05 ± 5.10	-0.12	0.427	0.987	0.121
	Iso-inertial	5.97 ± 5.29	7.07 ± 5.84	0.15			
	Cable resistance	7.97 ± 3.95	5.03 ± 4.16	-0.40			
HT ($km \cdot h^{-1}$)	All	69.82 ± 6.60	70.91 ± 6.50	0.41	0.015	0.181	0.015
	Iso-inertial	70.76 ± 1.18	72.94 ± 7.33*	0.88			
	Cable resistance	68.88 ± 6.04	68.88 ± 4.97	0.00			

Data are presented as mean ± SD. D: dominant leg; ND: non-dominant leg; cm: centimeters; s: seconds; ASY: inter-limb asymmetries; UCMJ: Unilateral countermovement jump; ULJ: Unilateral lateral; UBJ: Unilateral broad jump; HT: Handball throwing test.

Significant Cohen's *d* and *p*-values ($p \leq 0.05$) are shown in bold.

* $p_{Bonferroni} \leq 0.05$ different to baseline values.

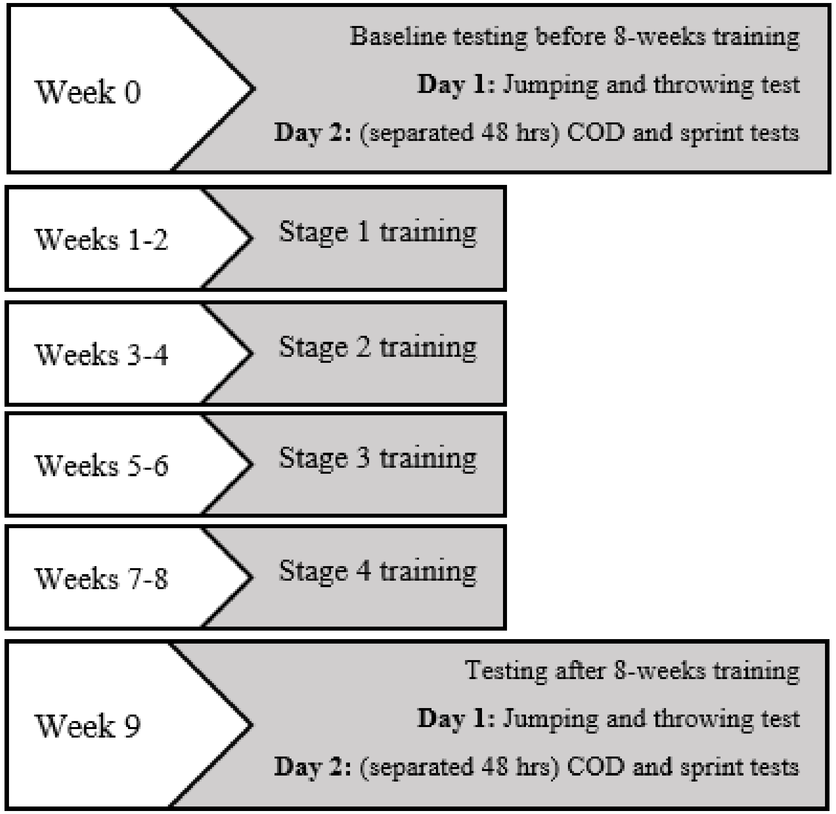

Figure 1. Testing timeline; COD: change of direction.

Figure 2. Cable resistance training (A) and iso-inertial training (B).

Figure 3. 8-weeks resistance training exercises and stimuli, following iso-inertial and cable resistance groups. UCMJ: unilateral countermovement jump.