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Change of Direction Ability as a Sensitive Marker of Adaptation to Different Training Configurations, and Different Populations: Results from Four Experiments

by
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This article includes four separate experiments. In the first experiment male beach handball players (n = 24) were randomly assigned to regular training (n = 12) or plyometric and sprint training (n = 12). In the second experiment, male players were assigned to a handball practice only (n = 12), a plyometric training (n = 12), or an eccentric-overload (e.g., versa-pulley machine) training group (n = 12). In the third experiment, participants were assigned to padel training (n = 12) or specific on-court neuromuscular technical actions (n = 12). In the fourth experiment, females between 50–59 years (n = 25), 60–64 years (n = 25), and 65–70 years (n = 25) completed 10 weeks of bench stepping training involving jumps, and were compared to age-matched controls (n = 45). The COD ability was assessed with the 10-m COD ability test (experiments one and two), the COD ability test with 90º and 180º turns (third experiment), and with the timed-up-and-go test (fourth experiment). In experiment one, greater COD improvement was noted in the experimental group compared to the control group (p < 0.05). In experiment two, both intervention groups similarly improved COD when compared to the control group (p < 0.05). In experiment three, although no significant group-time interactions were observed for COD, the experimental group improved all COD measures pre-post-training (p < 0.05), with a larger effect size for COD with 180° turn to the right compared to the control group (effect size = 0.8 vs. 0.3). In experiment four, the three training groups improved COD ability compared to the control group (p < 0.05). In conclusion, COD is a sensitive marker of adaptation to different training configurations in these diverse groups.

Key words: *plyometric exercise, musculoskeletal and neural physiological phenomena, human physical conditioning, team sports, movement, resistance training.*

Introduction

Change of direction (COD) performance is a motor ability that is important for success in different sports. For instance, team-sport players reported to perform ~1,350 high-intensity activities such as accelerations/decelerations, jumps and COD manoeuvres every 4–6 s (Mohr et al., 2003). Additionally, maximal-intensity short-duration movements such as COD are common before scoring actions in team sports (Ari et al., 2021; Faude et al., 2012). Moreover, COD ability may help differentiate between players according to their competitive level (Lemos et al., 2020). Physiological traits such as muscular strength, power, speed, and the rate of force development have been correlated to COD performance across sex and sport groups, and also age groups (Brughelli et al., 2008; Sheppard and Young, 2006; Young and Farrow, 2006), including aged populations (Fragala et al., 2019). Furthermore, COD performance is linked to other athletic and physical fitness traits such as cognitive (motor

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learning), technical (biomechanics), as well as dynamic strength, jumping, and linear single-maximal or repeated sprinting (Ari et al., 2021; Asadi, 2016a, 2016b; Fernández-Fernández et al., 2022; Sheppard and Young, 2006). Therefore, to address COD ability, there is a need to seek safe and effective training methods.

Effective training methods to improve COD performance that have been reported in the scientific literature include plyometric-jump training (PJT), sprint training, eccentric overload training, neuromuscular training, among others (Alcaraz et al., 2018; Fernández-Rios et al., 2019; Holm et al., 2004; Ramirez-Campillo et al., 2020; Vogt and Hoppeler, 2014). Indeed, PJT has demonstrated favourable effects on a myriad of physical fitness outcomes, including COD (Asadi et al., 2016) and repeated sprint ability with COD (Ramirez-Campillo et al., 2019, 2020), in line with improvements in the physiological (Markovic and Mikulic, 2010) determinants of COD and associated physical fitness components such as maximal dynamic strength (Sáez de Villarreal et al., 2010), jumping (Sáez de Villarreal and Ramirez-Campillo, 2022), and linear sprint (Sáez de Villarreal et al., 2012). Furthermore, PJT seems safe and effective in athletes, as well as in older adults (Moran et al., 2018). Moreover, combined PJT and sprints seem highly effective (Aloui et al., 2022). As an alternative to PJT, eccentric-overload training using flywheel or versa-pulley inertial devices has been suggested as another effective training strategy for the optimization of both strength and power capacities (Vogt and Hoppeler, 2014). Compared to PJT, eccentric-overload training stimulates the stretch-shortening cycle, with an accentuated eccentric effort-load (Norrbrand et al., 2008), although without high ground impact forces (Chiu and Salem, 2006), reducing the risk of landing injuries. Additionally, sport-specific neuromuscular training may also contribute to reducing injuries, as well as to the improvement of COD ability.

However, the effects of the above-mentioned training methods on COD performance in different athletic populations and age groups are unclear. Furthermore, the effects of training interventions with a moderator approach, involving the comparison of two (or more) different training approaches or between different groups of participants (e.g., age groups) are underresearched. Therefore, in this article we addressed four separate (although related) aims from four separate experiments. In the first experiment, the authors aimed to compare the effects of sand-based combined plyometric and sprint training versus beach handball-only training on the COD ability of beach handball players. The second experiment was aimed at comparing the effects of handball-only training versus plyometric training or versus eccentric training, on the COD ability of handball players. The third experiment aimed to compare the effect of two different neuromuscular training programmes on the COD ability of male padel players. The fourth experiment aimed to compare the effects of 10 weeks of bench stepping training with jumps on the COD ability in three groups of women of different age.

Methods

Participants

The descriptive characteristics of participants in experiments one, two, three and four are presented in Table 1.

In experiment one and two, regular beach handball and handball training took place on Monday, Wednesday, Thursday, and Friday. Regular training involved mainly low-volume and moderate-intensity training sessions. The number of tournaments and matches completed by beach handball and handball players during the year previous to their enrolment in the study was ~6–7 and ~26–30, respectively. In experiments one and two, male beach handball players (n = 24; age 18–25 years, Spanish second division) and male handball players (n = 36; age 18–22 years, Spanish second division), respectively, were recruited during their pre-season preparation period. Participants in experiment one and two had no systematic background in strength and power training. After the initial measurements, players from experiment one were randomly assigned to a control group (n = 12) that only performed the regular beach handball training program, and to an experimental group (n = 12) that completed the regular beach handball training program plus a combined plyometric-jump and sprint training program. All training sessions were supervised by a certified strength and conditioning specialist. In experiment two, participants were randomized to a control group (n = 12; i.e., only performed handball training), a plyometric training group (n = 12), and an eccentric-overload group (n = 12).

In experiment three, male padel players (n = 24; age 22–23 years) were recruited during the initial part of the in-season period (i.e., just after the pre-season). Participants were randomized (A–B distribution, based on sprint performance) to regular padel training (i.e., control group, n = 12) or padel training performed with an integrated training approach (i.e., experimental group, n = 12). Participants trained and competed in the first padel division of their respective country, with experience in international competitions. Players were ranked between 1 and 100 in their respective national singles ranking, trained 16 ± 3 $h \cdot wk^{-1}$, with a training background of 4.0 ± 2.4 years, involving padel-specific training (i.e., technical and tactical skills), aerobic and anaerobic training (i.e., off-court exercises) and strength training. A typical training week included i) specific padel training with 5 technical exercise sessions such as hits from the back of the court, forehand and backhand, volley at the net, lobs, defensive and offensive movements, and tactical exercises; ii) physical conditioning with 2 strength training sessions and 2 speed and COD training sessions; and iii) a competitive match.

In experiment four, 120 female participants were recruited (age, 50–70 years; all had menopause). Participants had no background in bench stepping training, although they had been involved in regular recreational activities in the last three years before their enrolment in the experiment. Participants were age-matched, and randomized to a bench stepping training group or a control group (n = 45, age 50.0–70.0 years), including training groups of participants aged 50.0–59.9 years (n = 25), 60.0–64.9 years (n = 25), and 65.0–70.0 years (n = 25). The training groups completed 10 weeks of bench stepping training (involving jumps).

In all experiments, exclusion criteria were as follows: i) potential medical problems or an injury history of ankle, knee, or back pathology in the last three months prior to the study; ii) previous medical, drug or orthopaedic problems that compromised their participation or performance in this study; iii) any lower extremity reconstructive surgery in the past two years or unresolved musculoskeletal disorders. In all experiments, participants were instructed to maintain their daily habits (e.g., exercise, nutrition) for the whole duration of the study. In all experiments, before signing an informed consent document, all the participants were carefully informed about the experiment procedures, the potential risk and benefits associated with participation in the study. The study was conducted in accordance with the updated Declaration of Helsinki and approved by the ethics committee of the Pablo de Olavide University.

Measures

In all experiments, testing sessions (pre-post interventions) were performed at the same time of the day (±1 h) for each athlete. All tests were conducted on an indoor synthetic court, with the only exception for beach handball players from experiment one, where a sand surface was used. The same investigator tested all participants, and was blinded to participants' allocation. Participants were required to attend testing sessions well hydrated, without ingestion of stimulants (i.e., caffeine) in the previous 8 hours, and to avoid high-intensity exercise during the previous 24 hours.

10-m COD test. In experiment one and experiment two, players were familiarized with the testing procedure, as the test was routinely performed during their regular training and testing schedule. Before the COD test, participants conducted a standardized general warm-up (7 min of submaximal running and light dynamic stretching), plus a sport-specific warm-up (7 min of COD, sprints, jumps and heading, ball passing and dribbling), and 3 minutes of stretching (first static and then dynamic). After a few minutes of recovery, participants completed the COD ability test. The test consisted of four 60° CODs over 10 m (Meylan and Malatesta, 2009). Two types of the COD test were performed, with pre-activation (five jumps and five seconds of skipping; i.e., only in beach handball players from experiment one) and without activation (i.e., for both beach handball players from experiment one, and handball players from experiment two). The purpose of the pre-activation variation of the COD test was to determine if the intervention would be able to improve performance under post-activation potentiation conditions. Participants started the test using a standardized crouch start and commenced sprinting with a random sonorous sound. Infrared beams were positioned at the end of the 10-m distance to be measured with photoelectric cell (Muscle Lab. V7.18. Ergotest Technology, Langesund, Norway). Poles of approximately 1.5-m high were placed on the floor to indicate the change of direction. Participants were not allowed to touch the poles as they sprinted and changed direction. Participants had two practice trials performed at half speed to familiarize with the timing device. Two maximal and valid trials were completed and the best performance was used for the subsequent statistical analysis. Two minutes of rest were permitted between trials. The intraclass correlation coefficient (ICC) varied from 0.92 to 0.93 for the different groups in experiments one and two.

Left and right 90º and 180º COD test. In experiment three, players were familiarized with the testing procedure and conducted a standardized warm-up consisting of 10-min submaximal running, joint mobilization exercises, 10 body-mass full-squats, and a specific warm-up consisting of several submaximal trials before each test. The 90° COD ability over a distance of 5 m was measured by turning to the left and the right side, with the support of the contralateral leg to the turning side. The athlete's ability to perform a single, rapid 180° change of direction over a 5-m distance was measured using a modified version (stationary start) of the 505-agility test. Players assumed a preferred starting position and started voluntarily, sprinting with maximal effort without a racquet. Three trials for each turning side and angle (i.e., 12 total trials) were completed, with the best time recorded to the nearest 0.01 s with electronic timing gates (Microgate, Bolzano, Italy). Two minutes of rest were allowed between trials. The ICC was 0.86 to 0.88 for the different groups.

Timed up-and-go test. In experiment four, the COD ability was assessed with the timed up-and-go test (Podsiadlo and Richardson, 1991). Participants were familiarized with the testing procedure. Participants started from a seated position without pushing off with the arms, walked 3-m, performed a 180° COD, and returned to the initial seated position as fast as possible. The test was administrated using a chair without arms and with a seat height of 0.46 m. The chair, with rubber tips on the legs, was placed against a wall to prevent the chair from moving during the test. The test began with the participant seated in the middle of the chair, back straight, arms crossed at chest-level, feet shoulder-width apart and placed on the floor at an angle slightly back from the knees, with one foot slightly in front of the other to help maintain balance when standing. At the signal "go" the participant started the test. Three trials were completed with 90 s of inter-trial rest. The best performance trial was used for statistical analysis. The ICC was 0.86 to 0.92 for the different groups.

Training

In experiment one, beach handball players performed their pre-season regular training sessions four days per week (M-W-Th-F). The experimental group supplemented two of the four weekly sessions with a plyometric-sprint training program, with 40-min sessions on Monday and Thursday, during 9 weeks, while the control group underwent regular beach handball training. The experimental group performed exercises at maximal voluntary effort intensity, using player's own body mass as resistance. Each intervention training session involved 10 min of a standard warm-up (5-min submaximal running with several COD, dynamic stretching exercises for 5 min, and submaximal vertical-horizontal jump exercises), 25 min of plyometric-sprint training with technical drills, and 5 min of dynamic and static stretching exercises at the end of the session. Plyometric-sprint exercises involved squat jumps, skipping, double-leg hops, double-leg speed hops, side hops, and alternate leg bounds, plus a 15-m sprint after each jump exercise set. The inter-set rest was 1 min. Both groups trained on a sand surface where athletes regularly trained. A certified strength and conditioning specialist supervised all the training sessions to ensure proper exercise technique.

In experiment two, handball players usually performed their pre-season regular training sessions four days per week (M-W-Th-F). During 5 weeks of the pre-season, the experimental groups supplemented handball training with plyometric training or eccentric-overload training, applied before regular handball practices on Monday, Wednesday, and Friday. The control group underwent only regular handball training. Each intervention session lasted 60 min and consisted of the following components: 10 min of a standard warm-up (5-min submaximal running at ~6 $km \cdot h^{-1}$, several CODs, dynamic stretching exercises for 5 min, and two submaximal jump exercises), 45 min of the intervention (either plyometric training or eccentric-overload training), and 5 min of dynamic and static stretching exercises at the end of the session. Plyometric exercises consisted of countermovement jumps with (i.e., 10–15% of body mass) and without the external load, burpees, jump lunge, alternate leg bounds, double-leg speed hops, and medicine ball throws. Eccentric exercises consisted of the versa-pulley unilateral press and pull, versa-pulley elbow flexion and extension, YO-YO squat and YO-YO leg curl. The rest interval between sets was 3 min. The training load was quantified by analysing the rating of perceived exertion of all training sessions in both the plyometric training and the eccentric-overload training group, helping in the regulation of the progressive overload. The athlete's perceived exertion was measured 30 min after each training session using the 0–10 point Borg scale, with which participants were previously familiarized. The perceived exertion value was multiplied by the total duration of the training session (min), and the resultant value (e.g., 300, derived from a perceived exertion of 6 and the session duration of 50 min) was considered an arbitrary unit of measure for the magnitude of internal training load or the session rating of perceived exertion (sRPE). All sessions were completed on the same official synthetic handball court were athletes usually trained and competed, with participants using appropriate handball equipment.

In experiment three, both the control and the experimental group completed the same training exercises twice per week, during 60-min sessions, with an inter-session rest of 48–72 h, over 8 weeks. Each session included 10 min of a standard warm-up (5-min submaximal running, joint mobilization exercises for 5 min, and 20 vertical and 10 horizontal submaximal jumps), and 45 min of neuromuscular training involving plyometric, strength, COD and power-oriented exercises (e.g., CMJs, burpees, jump lunges, medicine ball throws and chest throws, 5+5 m sprints with 90–180º COD left-right, bird-dogs, front bridges, slide bridges), and 5 min for a cool down which included dynamic and static stretching exercises. Although both training groups performed the same exercises, with the same number of repetitions and intensity, the experimental group trained inside the padel court and finished all the neuromuscular exercises with a sport-specific technical action (i.e., the forehand groundstroke, backhand groundstroke, forehand volley, backhand volley, overhead, smash, and lob), while the control group performed neuromuscular exercises outside the court, but on the same surface, and sport-specific technical actions were completed at a different time during the training session and without the racket. The sRPE was assessed as in experiment two.

In experiment four, participants completed a bench stepping-training program involving jumps (plus movements such as stretch touch, lunges, grapevines and knee lifts) for three 60-min sessions per week (Monday, Wednesday, Friday) for a period of 10 weeks. Training sessions involved 15 min of a standard warm-up (10-min submaximal running and CODs, dynamic stretching exercises for 5 min), 40 min of bench stepping work (using music between 118–128 beats·min^{-1}), and 10 min of dynamic and static stretching exercises at the end of the session. The first week was used for familiarization with the basic movements of bench stepping. During each session, the heart rate was registered (Sports Tester, Polar Electro, Kempele, Finland), and aimed for participants to work at 60–70% of the heart rate reserve (Chodzko-Zajko et al., 2009). The same certified strength and conditioning coach supervised all training sessions. The control group did not receive treatment and was instructed to maintain their physical activity habits. Training was performed in a closed sport hall area with a stable temperature of 26ºC and 65% of humidity, on a synthetic surface.

In all experiments, a strength and conditioning specialist ensured proper exercise technique during the intervention-training sessions. Additionally, in all experiments training intensity/volume progressively increased. In experiment one, depending on the intervention training exercise, different progressive overload techniques were used. For example, for some intervention training exercises (e.g., double-leg pops from 40–60 cm + 15-m sprint), the intensity was kept at maximum during the whole intervention, while repetitions increased from 3 to 4 per session toward the end of the program. Alternatively, other exercises (e.g., alternative leg bounds + 15-m sprint) kept the number of repetitions constant (i.e., 3 sets of 10 repetitions), while increasing the load from 10 up to 20 kg using load vests. In experiment two, the plyometric training group progressively increased the number of repetitions per exercise (e.g., from 30 to 60 repetitions per session from the first toward the fifth week) or the load (e.g., from 10 to 15 in loaded CMJs). The eccentric-overload training group applied mainly a volume-based progressive overloads, i.e., most exercises increased from 3 sets of 5 repetitions at week 1 up to 3 sets of 10 repetitions at week 5. In experiment 3, both training groups applied mainly a volume-based progressive overload, with 3 sets of 5–30 repetitions (depending on the type of exercise) at week 1, and 3 sets of 10–60 repetitions at week 8. In experiment 4, participants completed the training session at 60–70% of the heart rate reserve.

Therefore, to attain the adequate progressive overload, participants had to perform movements with greater speed and/or mechanical effort (e.g., higher bench steps, faster music beats) as training weeks progressed, in order to keep the desired heart rate.

Statistical Analyses

For all experiments, the mean and standard deviation for the dependent variables were calculated and statistics were performed in SPSS statistical package software, version 24.0 (SPSS, Inc., Chicago, IL, USA), with the alpha level set at $p \leq 0.05$. Normal distribution of the data was verified with the Shapiro-Wilk test (n < 50) and with the Kolmogorov-Smirnov test (n > 50). Homogeneity of variance across groups was verified using the Levene's test. In experiment one, training-related effects were assessed using a mixed-design factorial analysis of variance with the contrast F of Snedecor. In experiment two, training-related effects were assessed using a three (plyometric vs. eccentric vs. control) × two (pre-post intervention) factorial analysis of variance with Bonferroni post-hoc comparisons. In experiment three, training-related effects were assessed using 2 x 2 factorial analysis of variance with the contrast F of Snedecor, with one between-group factor (experimental vs. control group) and one within-group factor (pre-post intervention). In experiment four, to assess training related effects, a four (groups) by two (times) factorial analysis of variance was conducted, with Bonferroni *post hoc* analysis. In all experiments the magnitude of change was assessed using Cohen's *d* effect size and was calculated as follows: the mean of the differences between the pre-test and the post-test scores was divided by the respective pooled SD. Effect sizes were interpreted as: <0.2 = trivial, 0.2–0.5 = small, >0.5–0.8 = moderate, and >0.8 = large (Cohen, 1988).

Results

The results are presented in Table 2. At baseline, no significant differences between groups were observed in COD ability in experiments one, two and three. In experiment four, significant differences were observed between age groups for the pre-test ($p < 0.05$).

In experiment one, greater COD ability improvement was noted in the experimental group compared to the control group, in both COD without ($p < 0.05$) and COD with pre-activation ($p < 0.05$).

In experiment two, the sRPE was similar for the plyometric training group (361 ± 12.2 AU; 95% confidence interval, 356–366) and the eccentric training group (370 ± 13.3 AU; 95% confidence interval, 362–377). Both intervention groups similarly improved COD ability when compared to the control group ($p < 0.05$).

Table 1. *Participants' descriptive characteristics.*

	Age (y)	Height (cm)	Body mass (kg)	Experience* (y)
EXPERIMENT 1				
Experimental group (n = 12)	23.0 ± 4.9	180.9 ± 6.0	79.1 ± 8.3	5.3 ± 3.2
Control group (n = 12)	24.3 ± 2.1	181.2 ± 4.4	81.2 ± 5.2	5.4 ± 2.4
EXPERIMENT 2				
Plyometric training (n = 12)	19.8 ± 2.2	178.3 ± 4.3	79.1 ± 8.3	6.2 ± 2.8
Eccentric training (n = 12)	20.5 ± 2.5	179.7 ± 3.7	81.2 ± 5.2	6.5 ± 2.8
Control (n = 12)	20.6 ± 1.6	180.2 ± 2.8	81.2 ± 5.2	6.3 ± 2.8
EXPERIMENT 3				
Experimental group (n = 12)	22.6 ± 1.4	182.7 ± 6.7	75.2 ± 10.2	4.1 ± 2.6
Control group (n = 12)	21.5 ± 1.8	181.3 ± 8.1	74.2 ± 11.8	4.3 ± 1.9
EXPERIMENT 4				
Experimental group aged 50.0 to 59.9 years (n = 25)	52.4 ± 4.1	163.2 ± 7.1	66.6 ± 7.8	
Experimental group aged 60.0 to 64.9 years (n = 25)	63.4 ± 3.2	162.7 ± 5.4	71.5 ± 8.9	
Experimental group aged 65.0 to 70.0 years (n = 25)	68.4 ± 2.3	164.3 ± 4.9	73.2 ± 2.1	
Control age-matched group (n = 45)	58.1 ± 3.1	165.4 ± 2.4	65.6 ± 4.2	

*: experience in competitive sport.

Table 2. *Change of direction (COD) ability pre- and post-intervention periods for experiments 1–4.*

	Pre	Post	Pre-post Δ%	Cohen´s *d*
EXPERIMENT 1				
10-m COD without pre-activation (s)				
Experimental group (n = 12)	4.92 ± 0.36	4.39 ± 0.32 [a]	10.77 [b]	1.47
Control group (n = 12)	4.93 ± 0.28	4.81 ± 0.21	2.43	0.42
10-m COD with pre-activation (s)				
Experimental group (n = 12)	4.90 ± 0.27	4.33 ± 0.47 [a]	11.53 [b]	2.03
Control group (n = 12)	4.94 ± 0.45	4.85 ± 0.12	1.82	0.20
EXPERIMENT 2				
10-m COD (s)				
Plyometric training (n = 12)	4.68 ± 0.56	4.35 ± 0.78 [a]	6.90 [b]	0.58
Eccentric training (n = 12)	4.63 ± 0.56	4.27 ± 0.55 [a]	7.77 [b]	0.64
Control (n = 12)	4.72 ± 0.36	4.62 ± 0.32	2.03	0.27
EXPERIMENT 3				
COD with a 90° turn to the right (s)				
Experimental group (n = 12)	2.37 ± 0.20	2.31 ± 0.21	2.53 [b]	0.30
Control group (n = 12)	2.26 ± 0.13	2.22 ± 0.18	1.76	0.31
COD with a 90° turn to the left (s)				
Experimental group (n = 12)	2.34 ± 0.10	2.28 ± 0.11	2.56 [b]	0.60
Control group (n = 12)	2.27 ± 0.11	2.19 ± 0.12	3.52 [b]	0.72
COD with a 180° turn to the right (s)				
Experimental group (n = 12)	3.14 ± 0.21	2.98 ± 0.17	4.93 [b]	0.76
Control group (n = 12)	3.05 ± 0.20	2.99 ± 0.16	1.96	0.30
COD with a 180° turn to the left (s)				
Experimental group (n = 12)	3.19 ± 0.21	3.06 ± 0.17	4.07 [b]	0.61
Control group (n = 12)	3.15 ± 0.17	3.04 ± 0.12	3.49 [b]	0.64
EXPERIMENT 4				
Timed up-and-go COD ability test (s)				
Experimental group aged 50.0 to 59.9 years (n = 25)	5.35 ± 0.3	4.09 ± 0.2 [a]	23.55 [b]	
Experimental group aged 60.0 to 64.9 years (n = 25)	6.80 ± 1.2	5.47 ± 0.9 [a]	19.55 [b]	
Experimental group aged 65.0 to 70.0 years (n = 25)	8.12 ± 2.2	6.80 ± 1.8 [a]	16.25 [b]	
Control age-matched group (n = 45)	6.60 ± 2.8	6.50 ± 1.9	1.51	

[a]*: denotes greater improvement compared to the control group (p < 0.05).* [b]*: denotes significant within-group pre-post improvement (p < 0.05). Note: the before and after intervention values are indicated as mean ± standard deviation.*

In experiment three, the sRPE was similar for the experimental training group (315 ± 15.8 AU; 95% confidence interval, 309–319) and the control group (303 ± 12.6 AU; 95% confidence interval, 295–301). No significant group-time interactions were observed for any of the four COD ability measurements. However, while the control group improved (time effect) only COD ability with a 90° turn to the left and COD ability with a 180° turn to the left ($p < 0.05$), the experimental group exhibited improvements in all four COD ability measures pre- to post-training ($p < 0.05$), with a meaningfully larger effect size for COD with a 180° turn to the right (effect size = 0.8) compared to the control group (effect size = 0.3).

In experiment four, the three training groups improved COD ability compared to the control group ($p < 0.05$).

Discussion

In the first experiment, our novel findings support the beneficial effects of sand-based plyometric training combined with sprint training on the COD ability of beach handball players. This result is in line with previous findings (Ahmadi et al., 2021; Aloui et al., 2022; Asadi et al., 2016b). The improvement in COD ability may be related to lower-limb improved power, the rate of force development, maximal strength, speed and reactive force (Brughelli et al., 2008; Young and Farrow, 2006). In handball in general, and in beach handball in particular, COD ability is a key element of physical performance due to the relatively reduced playing field dimensions and the sand surface, with COD actions frequently occurring during matches and potentially helping to discriminate between players' competitive levels (Lemos et al., 2020; Pueo et al., 2017). Therefore, a sand-based combined plyometric and sprint-training program used with beach handball players for 9 weeks induced improvements in COD ability during the pre-season.

In the second experiment, the main findings indicate that a 5-week pre-season plyometric training program or an eccentric-overload training intervention similarly improves COD ability in male handball players when compared to regular handball practice. The increased COD ability following plyometric training has been reported previously (Asadi et al., 2016b). The improvement achieved after eccentric training may be attributed to the fact that eccentric-overload exercises are characterized by a more forceful execution of the stretch-shortening cycle and greater muscle activity (Norrbrand et al., 2008), which may enhance mechanical power output and maximal strength performance. However, proper execution technique is required to attain the eccentric overload, entailing resisting the inertial force gently during the first third of the eccentric phase, and then applying maximal effort to stop the movement at the end of the range of motion (Berg and Tesch, 1994). In addition, contrary to traditional strength training, devices employed by the eccentric training group have been designed to provide a maximal resistance load during the full concentric phase (Nuñez Sanchez and Sáez de Villarreal, 2017), which could contribute to COD ability. Of note, both intervention groups used mostly exercises with vertical force predominance, while COD ability requires application of force in both vertical and horizontal directions (Wagner et al., 2017). Also it is worth noting that handball players usually perform a high number of COD movements during regular handball-specific training and competition, requiring regular sprinting, deceleration and acceleration efforts (Ortega-Becerra et al., 2020), potentially decreasing the room for further improvement in COD ability. Nonetheless, COD ability improved in both plyometric training and eccentric training groups (ES = 0.58–0.64) when compared to the control group. Considering the key role of COD ability for success in handball (Falch et al., 2020), improved COD ability may contribute to athletes competitive performance. Therefore, compared to regular handball training, 5 weeks of plyometric training or eccentric-overload training equally improved male handball players COD ability during the pre-season. Strength and conditioning professionals working with handball players may include plyometric and eccentric overload training in the pre-season to improve athletes' physical fitness. Both training methods proved to be safe, feasible, effective, and time-efficient. The reduced cost and equipment necessary to complete plyometric training may be of particular practical relevance to professionals working with large groups of athletes, particularly at the amateur level.

In the third experiment, the main findings indicate that an in-season 8-week integrated-training approach induced no significant group-time interactions for any of the four COD ability measurements. However, while the control group improved only COD ability with a 90° turn to the left and COD ability with a 180° turn to the left, the experimental group exhibited improvements in all four COD ability measures pre- to post-training, with a meaningfully larger effect size for COD with a 180° turn to the right compared to the control group. Padel players frequently perform repeated actions of maximal acceleration and rapid COD, usually involving short distances (e.g., 5–10 m) (Castillo-Rodríguez et al., 2014). Therefore, improvements in COD ability may contribute to padel player's competitive performance. Selecting the appropriate exercise for COD improvements is important. Combined neuromuscular training is an effective training method to improve muscular performance because it enhances the ability of subjects to use the elastic and neural (e.g., motor unit recruitment) benefits of the strength-shortening cycle (Aagaard et al., 2002). In addition, the rate of force development, power, and eccentric strength, the latter being a prevalent component in COD during the deceleration phase, potentially decrease ground reaction times and improve movement efficiency, therefore positively affecting

COD ability (Young and Farrow, 2006). Thus, elite male padel players can enhance COD ability after an in-season 8-week combined neuromuscular training program, consisting of strength, COD and power-oriented exercises, performed on-court and integrated with padel-specific technical skills and with the use of specific padel equipment (i.e., racquet). From a logistical perspective, the integrated-training approach was embedded easily into a traditional in-season technical and tactical training regime. Interestingly, COD improvements in both groups were present to the left side of the turn (COD ability with a 90° and a 180° turn to the left). As almost all the players were right-side dominant, training may have induced greater impact toward the non-dominant side. Nonetheless, to confirm current findings future studies should consider mechanistic measures (e.g., physiological, biomechanical) in order to provide potential explanations for the meaningfully larger effect size improvement in COD with a 180° turn to the right in the experimental group compared to the control group, and for the lack of significant group-time interactions.

In the fourth experiment, COD ability was assessed pre- and post-10 weeks of a low impact bench stepping training program, with a focus on jumps, for three different age groups of healthy females (age, 50–70 years). Compared to age-matched control participants, the three age groups improved COD ability. In accordance with previous findings (Ramirez-Campillo et al., 2017), we found that a training program with a focus on jumps (i.e., high-speed movements) induced a significant improvement in COD ability. Although improved gait stability and COD ability may be related to maximal strength (Krebs et al., 1998), muscle power is more closely associated with functional task performance (and risk of falling) in older women (Schoene et al., 2013). Therefore, muscle strength, and particularly power improvements may explain the COD ability improvement after the bench stepping training. The improvements may suggest reduced neuromuscular wasting processes, morphological and neural adaptations of the lower-limbs (Pinto et al., 2014), and better survival in the long-term (Studenski et al., 2011). Therefore, our results reinforce the notion that high-speed training can be useful in counteracting the neurological and morphological aging-associated wasting processes (Cadore and Izquierdo, 2018) and that key daily living functional performance tasks can be markedly improved with an adequate training intervention. Indeed, exercise programmes should be safe enough to avoid injuries and musculoskeletal consequences. This is especially important in programmes designed for middle-aged and older females. In experiment four, 7%, 12% and 15% of trained participants in the age groups 50.0–59.9, 60.0–64.9 and 65.0–70.0 years, respectively, reported either delayed onset of muscle soreness, stiffness, cramps, or muscle strains, although interruptions in training due to musculoskeletal symptoms were of short duration. Moreover, the incidence and severity of symptoms were reduced as the training program progressed.

In conclusion, in three of the four experiments, the intervention-trained groups achieved greater ($p < 0.05$) COD ability improvements when compared to control groups. Therefore, COD ability is a sensitive marker of adaptation to different training configurations (with a focus on rapid movements), and in diverse age, sex, and sport-related populations.

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