COMPARISON OF TWO 8-WEEK TRAINING INTERVENTIONS ON THE ATHLETIC PERFORMANCE OF PADEL PLAYERS

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Abstract:

Padel is an intermittent racket sport played in pairs (2 vs. 2) on a small-sized grass court (20 x 10 m), involving high physical fitness demands for the players. Therefore, this study aims to compare the effect of two 8-week in-season training programs on the athletic performance of male padel players. Participants (age, 22.1±0.8 yr; body height, 182.0±1.0 cm ; body mass, 74.7±0.7 kg) were randomly assigned to the integrated training group (IG, n=12) and non-integrated training group (NIG, n=12). The IG trained inside the padel court, integrating neuromuscular exercises with sport-specific (i.e., use of the racket) technical actions. The NIG trained outside the padel court, performing the same neuromuscular exercises and sport-specific technical actions as the IG, although not simultaneously. Before and after the intervention, athletes were assessed for their hand-grip strength, two legged and one-legged Abalakov jump, bench press performance, padel stroke velocity, cardiorespiratory endurance (30-15_{IFT}), 5-m and 10-m linear sprint time and change of direction ability at 90º and 180º using left and right leg. Both groups improved their scores on Abalakov jump tests, bench press performance, stroke velocity, cardiorespiratory endurance (30-15_{IFT}), and change of direction ability at 90º and 180º (all changes p<.05; effect size = 0.22-2.58). The IG improved stroke velocity compared to NIG (p<.05), and only the IG showed pre-post improvements (p<.05; effect size = 0.30-0.76) in change of direction ability at 90º and 180º involving the non-dominant leg (i.e., turn to the right). An 8-week in-season integrated training approach and a non-integrated training approach may induce similar improvements in athletic performance among highly trained male padel players. However, the neuromuscular training program involving an integration of padel-specific and non-specific training exercises may induce greater improvements in padel-specific performance (i.e., stroke velocity) and change of direction speed ability, particularly in movements involving the non-dominant leg.

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

Introduction

Padel is an intermittent racket sport played in pairs (2 vs. 2) on a small-sized grass court (20 x 10 m) surrounded by glass and mesh walls. Rallies last ~9 seconds, involving 15-20 actions and strokes per player, a greater demand compared to racket sports like badminton, tennis, or squash (Courel-Ibáñez, Sánchez-Alcaraz Martínez, Benítez, & Echegaray, 2017a; Courel-Ibáñez, Sánchez-Alcaraz Martínez, & Munoz Marin, 2019; Courel-Ibáñez, Sánchez-Alcaraz, & Cañas, 2017b). Due to the exponential growth of the popularity of padel in the last few years, several studies have been published aiming to describe the activity profile of the sport, as well as its physical and physiological demands (Carrasco, Romero, Sañudo, & de Hoyo, 2011; Courel-Ibáñez, et al., 2017a, 2017b; Courel-Ibáñez, et al., 2019). Previous studies examining its game dynamics and match activity have defined padel as a high-intensity intermittent activity, which combines high-frequency (0.7–1.5 per second) of high-intensity and low-intensity actions, during rallies that are of a moderate duration (9–15 seconds), interspersed by 1,020 seconds of rest in between, leading to longer breaks of 90 seconds (Carrasco, et al., 2011; García-Benítez, Courel-Ibáñez, Pérez-Bilbao, & Felipe, 2018; Torres-Luque, Ramirez, Cabello, Nikolaidis, & Alvero Cruz, 2015). In addition, the average heart rate during a game was 148±13.7 beats per minute (73.9±4.6% of the maximal heart rate), with values up to 169±18.4 beats per minute (Carrasco Páez, de Hoyo, & Sanudo, 2007), with some variations depending on contextual factors (Roldán-Márquez, Onetti-Onetti, Alvero-Cruz, & Castillo-Rodríguez, 2022). Padel and tennis players demonstrate a similar VO_{2max} ((Ferrauti, Kinner, & Fernandez-Fernandez, 2011)).

Furthermore, physical fitness (including padel-specific markers) has high impact on determining padel players' performance at professional and non-professional levels, independent of sex or age (Courel-Ibáñez & Llorca-Miralles, 2021; Courel-Ibáñez, et al., 2019; Escudero-Tena, Sánchez-Alcaraz, García-Rubio, & Ibáñez, 2021; Müller & Del Vecchio, 2018; Pradas, Sánchez-Pay, Muñoz, & Sánchez-Alcaraz, 2021; Pradas, et al., 2022), and may help to reduce the risk of injury (Demeco, et al., 2022). In this sense, the increasing intensity of sport competitions make strength and conditioning training a priority for success (Gale-Watts & Nevill, 2016). However, the effects of strength and conditioning methodologies involving padel-specific (integrated model) and non-specific exercises, that target the optimization of a comprehensive number of key athletic performance markers (strength, power, endurance, sport-specific performance, acceleration, and change of direction [COD] ability), have not been explored in high-level male padel players. Therefore, and in line with recent recommendations for more research in this field (García-Giménez, Pradas de la Fuente, Castellar Otín, & Carrasco Páez, 2022), the purpose of this study was to examine the effect of two different combined neuromuscular training methods (i.e., a combination of plyometric, strength, COD, and power-oriented exercises) applied to two training intervention groups (integrated vs. non-integrated) on the athletic performance of high-level male padel players. It was hypothesized that such training methods would lead to increases in athletic performance gains of the two training intervention groups (integrated vs. non-integrated) but in different ways.

Methods

Study design

This study was designed to examine how integrated and non-integrated physical training interventions affected padel-specific performance parameters. This study was conducted during an 8-week (16 sessions) padel in-season training period with padel players. After initial measurements, participants were randomly assigned (A–B distribution, based on their sprint performance) to the following two training intervention groups: integrated training group (IG, n = 12), and non-integrated training group (NIG, n = 12). Physical performance was assessed before (Pre) and after (Post) the 8-week training period using a battery of tests as follows: (a) anthropometric measures, (b) hand-grip strength test in both hands (right [HGR] and left [HGL], (c) Abalakov jump test bipodal (ABK) and monopodal with the right leg (ABKR) and the left leg (ABKL), (d) 10 meter linear sprint time test (10-m), (e) stroke velocity test (SV), (f) bench press test (BP), (g) 30-15 Intermittent Fitness Test (30-15IFT), and (h) change of direction test at 90º with the right leg (COD90R) and left leg (COD90L) and at 180º with the right leg (COD180R) and left leg (COD180L). All tests were conducted on an indoor synthetic court. Participants were instructed to avoid any additional strenuous physical activity not related to the training interventions and to maintain their usual dietary habits and their normal padel training sessions for the duration of the study.

Participants

A total of 24 licensed male padel players (participants' characteristics provided in Table 1) volunteered to participate in the present study.

Participants belonged to the same club that competed both at the national (First Spanish padel division) and international level. The players were ranked between 1 and 100 in their respective national singles ranking; they trained 16 ± 3 $h.wk^{-1}$ and had a training background of 4 ± 2.4

Table 1. Participants characteristics

	Age (years)	Height (cm)	Body mass (kg)	Playing experience* (years)
IG = 12	22.6 ± 1.4	182.7 ± 6.7	75.2 ± 10.2	4.1 ± 2.6
NIG = 12	21.5 ± 1.8	181.3 ± 8.1	74.2 ± 11.8	4.3 ± 1.9

Note. Values are reported as mean ± standard deviation. *: in the first Spanish padel division.
IG: integrated training group; NIT: non-integrated training group.

years, which focused on padel-specific training (i.e., technical, and tactical skills), aerobic and anaerobic training (i.e., on and off-court exercises) and strength training. All the participants were familiarized with the testing exercises. A detailed description of the typical training week included the following: specific padel training (five sessions with technical exercises: hits from the back of the court, forehand and backhand, volley at the net, lobs, defensive and offensive movements, and tactical exercises); physical conditioning (four sessions, out of which two strength training sessions and two focused on speed and agility development); and competitive play (one game per week), totaling ~16 hours per week on average. Data collection took place during the two months (i.e., the in-season training period) of the season. Before participating in this project, which was approved by the institutional ethics review committee, participants were fully informed about the protocol and were required to give their written consent in accordance with the Declaration of Helsinki II. Also, participants completed a questionnaire regarding their medical history, age, body height, body mass, training characteristics, injury history, padel experience, and performance level. In addition, before their participation in this study, the players had a medical examination to determine whether there were any orthopedic or other conditions that would preclude them from high-intensity training.

Testing procedures

All the participants were familiarized with the test procedures two weeks before the pre-testing sessions. The tests were conducted over a 2-day period. To account for diurnal effects, all testing sessions were performed at the same time of the day (±1 h) for each athlete. On day 1, the tests were completed in the following order: anthropometric measures, vertical ABK jump, and muscular strength in hand grip and BP exercises. On day 2, SV, 10-m sprint time, COD in 90º and 180º and 30-15IFT tests were completed. Before testing, participants carried out a standardized warm-up consisting of 10-minute submaximal running at 9 km.h^{-1} followed by joint mobilization exercises, 10 full-squats with their own body mass (no external loads), and a specific warm-up consisting of several submaximal trials before each test. Verbal encouragement was provided to each participant during the testing sessions.

Hand-grip strength. Hand-grip strength was measured using a hand dynamometer (T.K.K. 5401 Grip D®, Takei Scientific Instruments, Japan). Participants were standing with their arms flexed. They were asked to perform a maximal voluntary contraction standing with the dynamometer at one side (i.e., the dominant hand) and squeezing the dynamometer as hard as they could for three seconds. This was repeated for each hand (i.e., the dominant and non-dominant hand). The maximum voluntary handgrip strength was obtained from two trials for each hand.

Abalakov jump. The ABK jump height was calculated from flight time values determined using an infrared timing system (Optojump®, Microgate France, 38330 St. Ismier). The ABK jump was assessed bipodal (ABK) as well as monopodal with both legs (ABK-R and ABK-L). Three trials were completed with 2-minute rests between each trial. The mean of the three trials was then used for subsequent statistical analyses.

10-meter sprint time. Sprint times were recorded for a 10-meter distance (with 5-meter split time) indoors on the synthetic surface. The participants started the test using a crouch start and commenced sprinting upon a random sonorous sound. Infrared beams were positioned at the sprint distance to be measured with photoelectric cell (Microgate®, Bolzano, Italy). After a warm-up (5-minute jogging, stretching exercises, squats, and two 20-m and 10-m sprints), the participants were given two practice trials performed at half speed to familiarize them with the timing device. Then two test trials were completed, and the best trial performance was used for the subsequent statistical analysis. Three minutes of rest was permitted between the 10-meter trials.

Stroke velocity. A radar gun (Stalker Professional Sports Radar®, Radar Sales, Plymouth, MN, USA) was used to measure SV (smash velocity; km.h^{-1}). On the padel court, the radar gun was placed 2-m behind each participant (Ramos Veliz, et al., 2015). Valid trials involved the ball that hit the synthetic-glass background panel (after one bounce off the court). With this aim, cones were placed at one meter from the dividing line (central service line) and from the side-line (Figure 1). Players received the balls from another player sending lobs. The set of balls was placed at two meters, in crossed direction with the position of the participants, from the dividing net and they stood at two meters from this net. Once a warming up of the stroke-involved joints was done and five soft strokes were made, the speed was measured for five consecutive strokes made. The same ball conditions were used to carry out the post-tests (Head CS, Amsterdam, NL). For later statistical analysis, the highest and lowest values were eliminated and the average was calculated from the three remaining values.

Muscle strength in BP. Participants performed the BP by lowering the bar from a fully extended arm position until the bar was at the chest height, but did not touch it, and then immediately they extended their arms as fast as possible to return the bar to the starting position (Martin, Pareja Blanco, & Sáez de Villarreal, 2021). All BP tests were performed in a Smith machine (Adan Sport®, Granada,

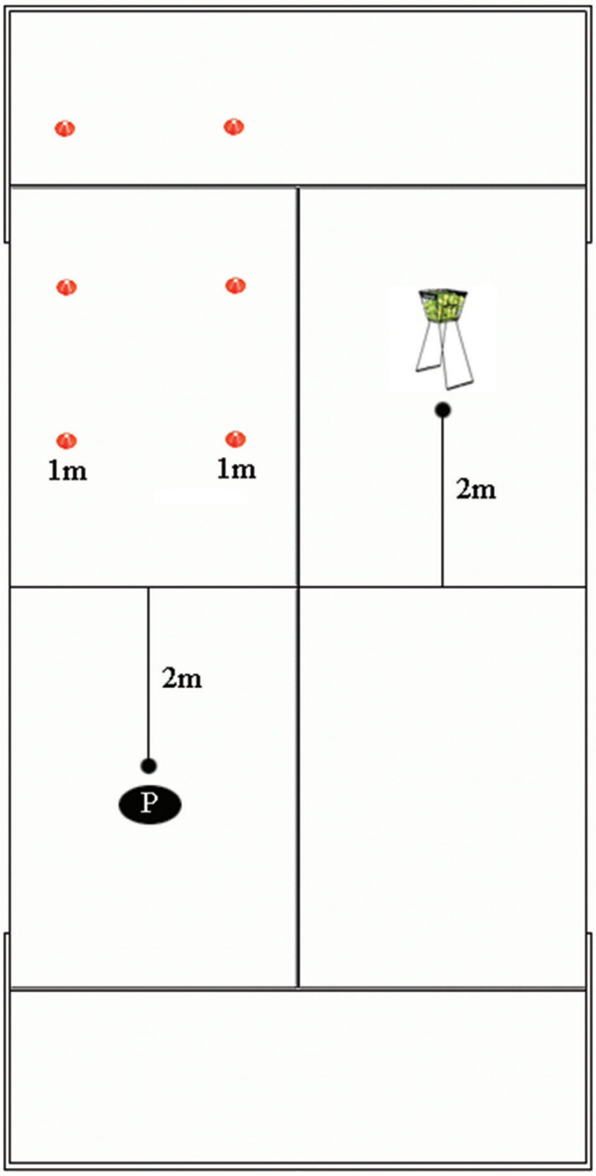

Figure 1. Schematic representation of the power shot test for velocity. "P" denotes the position of the player on the court.

Spain). The Smith machine was instrumented with a linear encoder, which was attached to one end of the bar to determine bar velocity (in meters per second) at 1000 Hz (T-Force System®; Ergotech, Murcia, Spain). The reliability of this device has been reported elsewhere (Sánchez-Medina & González-Badillo, 2011). Two sets of eight and four repetitions with 20 and 40 kg, respectively, were performed before testing as a warm-up protocol. Three maximal repetitions were performed against 50 kg. The fastest velocity values attained with 50 kg in BP (BP-50 kg) were recorded for further analysis. The rest period between trials was maintained at two minutes. All velocities reported in this study refer to mean propulsive velocity, which is defined as the fraction of the concentric phase during which barbell acceleration is greater than the acceleration due to gravity (Sanchez-Medina, Perez, & Gonzalez-Badillo, 2010).

30-15 intermittent fitness test. Supra maximal intermittent performance with changes of direction was assessed using the 30-15IFT (Buchheit, 2008), which consisted of 30-second shuttle runs interspersed with 15-s passive recovery periods. The athletes had to run back and forth between two lines set 40 meters apart at a pace dictated by an auditory signal. The speed was set at 8 km.h^{-1} for the first 30-second run and was increased by 0.5 km.h^{-1} every 45-second stage thereafter. The speed during the last completed stage was noted as the velocity obtained in the intermittent fitness test (VIFT).

90º and 180º change of direction. The athlete's ability to perform a single, rapid 90° and 180° COD using the right or left leg was measured, with a modified version of the 505-agility test, as previously described (Gabbett, Kelly, & Sheppard, 2008). Briefly, players assumed a preferred foot behind the starting position line and accelerated voluntarily, sprinting with maximal effort without a racquet over 5-meter distance, and then performed a 90° or 180° COD with the left or right leg (COD90L, COD90R, COD180L, and COD180R, respectively) for a final 5-meter sprint. The time was recorded to the nearest 0.01 second using electronic timing gates (Microgate®, Bolzano, Italy). Three trials were completed for COD90L, COD90R, COD180L, and COD180R. The best of the three trials was used for subsequent statistical analysis. Two minutes of rest were allowed between trials.

Training procedures

The descriptive characteristics of the integrated and non-integrated training program are presented in Table 2. The two groups trained twice a week (training sessions being 48–72 hours apart) for eight weeks, before usual padel training. Each session lasted 60 minutes, consisting of 10 minutes of standard warm-up (5-minute submaximal running at 9 km.h^{-1}, mobilization exercises for 5-min, and two submaximal jump exercises [20 vertical jumps and 10 long jumps]), 45 minutes of combined neuromuscular training (a combination of plyometric, strength, COD, and power-oriented exercises) for each group, and five minutes of cool down including stretching exercises. Integrated group (IG) trained inside padel court and finished all the combined neuromuscular exercises proposed with a specific technical execution of game actions (i.e., forehand ground stroke, backhand ground stroke, forehand volley, backhand volley, overhead, smash, lob). Non-integrated group (NIG) realized neuromuscular training outside the court, but on the same surface, without technical execution of game actions and without the racket. The training load was quantified by analyzing the rating of perceived exertion (RPE) of each session. Each participant's session RPE was collected 30 minutes after each training session using Borg scale-10 (Borg, Hassmén, &

Lagerström, 1987), with which they were previously familiarized. Then, RPE value was multiplied by the total duration of training (minutes) to represent in a single number the magnitude of internal training load in arbitrary units (AU) (Foster, et al., 2001). The total duration of specific training for all the groups was controlled and was similar (45 minutes) for each group. All training sessions for both groups were fully supervised, and training diaries were maintained for each participant. All the players completed all the training sessions.

Statistical analysis

Descriptive statistics (mean ± standard deviation) for different variables were calculated. The intraclass correlation coefficient (ICC) was used to determine the reliability of the measurements. Homogeneity of variance across the groups was verified using the Levene's test, whereas the normality of distribution of the data was examined with the Shapiro-Wilk's test. Data were analyzed using a 2x2 factorial analysis of variance with the contrast F of Snedecor one between-group factor (IG vs NIG) and one within-group factor (pre-training vs. post-training). The effect size (ES) values were calculated using Hedges's *g*, as a ratio of the difference between two means divided by the combined estimate of the standard deviation (Rosnow & Rosenthal, 2003). Statistical significance was accepted at an alpha level of $p \leq .05$. The SPSS statistical package, version 24.0 was used (SPSS, Inc., Chicago, IL, USA).

Results

All measurements were considered reliable based on the ICC values for the tests, as follows: HG: 0.94 (95% confidence interval [CI], 0.92 to 0.96); ABK: 0.91 (95% CI, 0.89 to 0.93); BP: 0.92 (95% CI, 0.90 to 0.94); SV: 0.90 (95% CI, 0.88 to 0.92); 30-15 IFT: 0.89 (95% CI, 0.87 to 0.91); SP: 0.87 (95% CI, 0.85 to 0.89); COD: 0.87 (95% CI, 0.84 to 0.90).

No significant differences ($p > .05$) were observed after training in the session RPE between the groups: IG = 315.5 ± 15.8 AU (95% CI, 308.8–318.8), and NIG = 302.6 ± 12.6 AU (95% CI, 295.4–3010.4).

At baseline, no significant differences ($p > .05$) were observed between the groups in any of the performance variables tested (Table 3).

Table 2. Description of the different training programs performed by each experimental group

Exercises	W1	W2	W3	W4	W5	W6	W7	W8
	S1-S2	S3-S4	S5-S6	S7-S8	S9-10	S11-S12	S13-14	S15-S16
INTEGRATED GROUP (IG)								
CMJ + smash	3x15	3x15	3x15	3x15	3x20	3x20	3x20	3x20
Burpee + forehand volley	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
Burpee + backhand volley	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
Jump lunge + smash	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
5+5 m 90º left + volley	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
5+5 m 90º right + volley	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
5+5 m 180º + lob	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
NON-INTEGRATED GROUP (NIG)								
CMJ	3x15	3x15	3x15	3x15	3x20	3x20	3x20	3x20
Burpee	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
Burpee	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
Jump lunge	3x5	3x6	3x7	3x8	3x9	3x10	3x10	3x10
5+5 m 90º left	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
5+5 m 90º right	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
5+5 m 180º	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
COMMON EXERCISES FOR BOTH GROUPS								
MB throw (kg)	3x10x1	3x10x1	3x10x1	3x10x2	3x10x2	3x10x2	3x10x3	3x10x3
MB chest throw (kg)	3x10x5	3x10x5	3x10x5	3x10x7	3x10x7	3x10x7	3x10x10	3x10x10
Bird-dog	3x10	3x10	3x12	3x12	3x12	3x15	3x15	3x15
Front bridge (s)	3x30	3x30	3x30	3x45	3x45	3x45	3x60	3x60
Side bridge (s)	3x30	3x30	3x30	3x45	3x45	3x45	3x60	3x60

Note. CMJ: countermovement jumps; MB: medicine ball (one-handed overhead throwing technique involving MB of 1, 2 or 3 kg. The MB chest throw involving up to 10 kg MB); S: session; W: week; 5+5 m 90º: 5 m front sprint, turn, and 5 m sprint to the left or right side; 5+5 m 180º: 5 m front sprint and 5 m back sprint. A rest period between sets of 90 seconds was used for all exercises.

Table 3. Performance variables of pre-test and post-tests for experimental groups

	Integrated group (n = 12)				Non-integrated group (n = 12)			
	Pre-test	Post-test	Δ%	ES	Pre-test	Post-test	Δ%	ES
HGR (kg)	51.39 ± 6.45	53.17 ± 6.24	3.46	0.27	54.86 ± 5.68	55.13 ± 4.66	0.49	0.04
HGL (kg)	48.06 ± 6.24	48.81 ± 6.09	1.56	0.12	46.94 ± 4.36	47.52 ± 4.18	1.23	0.13
ABK (cm)	37.77 ± 7.59	40 ± 6.24 *	5.90	0.29	41.21 ± 5.07	43.60 ± 3.98*	5.79	0.47
ABKR (cm)	20.17 ± 4.42	21.16 ± 3.95 *	4.90	0.22	22.64 ± 4.07	24.80 ± 2.99 *	9.54	0.53
ABKL (cm)	19.77 ± 5.30	21.64 ± 4.18 *	9.45	0.35	20.72 ± 3.91	23.04 ± 3.87 *	11.19	0.59
BP (m/s)	1.24 ± 0.14	1.43 ± 0.13 *	15.32	1.35	1.27 ± 0.18	1.44 ± 0.08 *	13.38	0.94
PS ($km.h^{-1}$)	132.95 ± 8.95	156.05 ±6.53 * $	17.41	2.58	133.43 ± 12.37	145.10 ± 11.30*	8.74	0.94
30-15 ($km.h^{-1}$)	20.43 ± 1.62	21.93 ± 1.37 *	7.34	0.92	21.57 ± 1.51	22.86 ± 0.90 *	5.98	0.85
SP5 (s)	1.12 ± 0.13	1.09 ± 0.06	2.67	0.23	1.05 ± 0.06	1.04 ± 0.09	0.95	0.17
SP10 (s)	1.97 ± 0.19	1.96 ± 0.16	0.50	0.05	1.95 ± 0.09	1.93 ± 0.12	1.02	0.22
COD90R (s)	2.37 ± 0.20	2.31 ± 0.21*	2.53	0.30	2.26 ± 0.13	2.22 ± 0.18	1.76	0.31
COD90L (s)	2.34 ± 0.10	2.28 ± 0.11*	2.56	0.60	2.27 ± 0.11	2.19 ± 0.12 *	3.52	0.72
COD180R (s)	3.14 ± 0.21	2.98 ± 0.17 *	4.93	0.76	3.05 ± 0.20	2.99 ± 0.16	1.96	0.30
COD180L (s)	3.19 ± 0.21	3.06 ± 0.17*	4.07	0.61	3.15 ± 0.17	3.04 ± 0.12 *	3.49	0.64

Note. Values are reported as mean ± standard deviation. ABK = Abalakov jump bipodal; ABKL and ABKR = Abalakov jump with left and right leg, respectively; BP = bench press; COD90L, COD90R, COD180L, and COD180R = change of direction 90° and 180° to the left and right, respectively; ES = effect size; HGL and HGR = hand grip left and right hand, respectively; PS = power shot; SP5 and SP10 = sprint 5 and 10 meters, respectively; 30-15 = 30-15 intermittent fitness test. * = denotes significant differences between pre-training and post-training (p<0.05); $ = denotes significant differences between groups after training (p<.05).

There were no significant pre-post intervention improvements (within-group changes) in any group for HGR, HGL, SP5, and SP10 (Table 3). However, both training groups exhibited significant improvements (p<.05; ES = 0.22 – 2.58; Table 3) in ABK, ABKR, ABKL, BP, PS, 30-15 IFT, COD 90L, and COD 180L.

Only the IG improved COD 90R and COD 180R (p<.05; ES = 0.30 – 0.76; Table 3). Further, compared to the NIG, a greater (p<.05) improvement in PS was noted in the IG (Table 3).

Discussion and conclusion

Both NIG and IG training groups experienced similar improvements in athletic performance after eight weeks of intervention. However, compared to the NIG training approach, the IG training approach induced greater improvements in padel-specific performance (i.e., PS). Further, CODs performance improved in the IG, particularly in actions involving the non-dominant leg (i.e., left). A discussion of these findings is provided in the paragraphs that follow.

Vertical jump performance (ABK bipodal and monopodal) has been the focus of attention in previous literature and in several individual and team sports, using a myriad of training methods (Arabatzi, Kellis, & Sáez de Villarreal, 2010; Saéz de Villarreal, Suarez-Arrones, Requena, Haff, & Ramos-Veliz, 2014; Sáez de Villarreal, Suarez-Arrones, Requena, Haff, & Ramos Veliz, 2015). In the present study, both training methods induced a positive stimulus in ABK performance. In agreement with our findings, a previous study (Fernandez-Fernandez, Saez de Villarreal, Sanz-Rivas, & Moya, 2016) reported that plyometric training, specific tennis training or combined training meaningfully increased vertical jump ability. It is conceivable that specific neuromuscular training, which involves specific technical execution of game actions (forehand and backhand volleys, smash strokes, lobs) used in padel skills, allows players to improve their jumping ability. However, our findings suggest that isolated and analytic neuromuscular training without technical actions may provide enough stimulus to improve jump performance (ABK bipodal and monopodal) in young male padel players.

In agreement with the previous literature (Salonikidis & Zafeiridis, 2008) our findings indicated that combined neuromuscular training significantly increased strength performance (BP) in padel players. However, there were no improvements in HGR or HGL in both groups. This finding may be explained by the fact that hand grip strength gain is an action that needs strength development in a specific zone (forearm musculature) rather than a technical skill. Hence, the addition of power-oriented exercises (burpees) with an emphasis on high velocity execution during the exercises seems to provide a positive stimulus for improving BP in young male padel players.

Hitting power of the ball is an important skill in padel, and high accuracy and control in the overhead stroke is an essential component of smashing and volleying for the purpose of scoring points. The faster and more accurately the ball can be struck, the less time opponents have in returning the ball. Several studies on overarm hitting have identified that several factors, including upper and lower limb and trunk strength, stroking technique and vertical jumping ability affect SV (Fernandez-Fernandez, Kinner, & Ferrauti, 2010; Fett, Ulbricht, & Ferrauti, 2020; Palmer, Jones, Morgan, & Zeppieri, 2018). Previous studies have reported that general resistance and ballistic training, including upper and lower body exercises, induces positive adaptations in SV ((Baiget, Corbi, Fuentes, & Fernández-Fernández, 2016; Fett, et al., 2020; Palmer, et al., 2018). Our results concur with those studies showing that a combined strength and power-oriented training program can significantly increase overhead SV performance (8-17%, p<.05). The high relationship between force and SV (Colomar, Baiget, & Corbi, 2020; Ramos Veliz, Requena, Suarez-Arrones, Newton, & Sáez de Villarreal, 2014) lends support to the theory that SV is also influenced by lower body force enhancing the capacity to improve hitting power. However, power alone is unlikely to be sufficient in less-skilled players whose lower limb strength is not as proficient (Courel-Ibáñez & Llorca-Miralles, 2021; Courel-Ibáñez, et al., 2019; Escudero-Tena, et al., 2021; Müller & Del Vecchio, 2018; Pradas, et al., 2021, 2022). Knowledge of the game also suggests that ability to prepare the technical gesture (i.e., volley, smash, drop, and lob) would increase strategic options for players during competition.

From a physiological point of view, the importance of the aerobic capacity in padel, as a basis for the correct use of different anaerobic energy channels and for a better inter-effort recovery, is highly proven (Castillo-Rodríguez, Alvero-Cruz, Hernández-Mendo, & Fernández-García, 2014). For example, an average heart rate of 148±13.6 beats per minute and demands of 43.7% of VO2max during games was reported in young male players from national category (Carrasco Páez, et al., 2007). These average heart rate values are similar, although a bit lower, to those studied in tennis (Fernandez-Fernandez, et al., 2010), possibly because padel is, compared to individual tennis, played in pairs and the points are longer with more strokes per point but at a lower intensity (Sánchez-Alcaraz Martínez, Pérez González, & Pérez Llamazares, 2013). However, the average heart rate as an intensity indicator does not reflect the interval character of a padel match (Courel-Ibáñez, et al., 2019). Therefore, due to the aerobic-anaerobic requirements considering in the padel time structure, a specific high-intensity interval exercise was introduced in our research to improve the aerobic capacity of the player. Our results showed improvements (p<.05) in 30-15IFT in both experimental groups. However, the training methodology that achieved the greatest improvements in 30-15IFT was IG (7.3%, p<.05). Therefore, this type of specific neuromuscular training (plyometric, COD and power-oriented exercises), either IG or NIG, could improve oxidative capacity, recovery between efforts, the reserve anaerobic capacity and the neuromuscular fatigue of the young padel players.

Padel players frequently perform repeated actions of maximal acceleration and rapid COD, most of which are very short-duration efforts over 5-10 meters (Castillo-Rodríguez, et al., 2014). Additionally, positive results in sprint ability have been obtained when strength training was combined with plyometric training (Delecluse, et al., 1995; Kotzamanidis, Chatzopoulos, Michailidis, Papaiakovou, & Patikas, 2005) or when plyometric training was applied alone (Meylan & Malatesta, 2009). However, even though padel players significantly increased jumping, strength and endurance ability, the results of the current investigation did not show that a combined neuromuscular program (plyometric, strength, COD, and power-oriented exercises) significantly improved sprint time performance (0.5-2.6%, p>.05). Acceleration and sprint performance are related to factors such as stride rate, stride length, technical skills, anthropometric characteristics, genetic factors, maximal strength, rate of force development, and power (Mero, Komi, & Gregor, 1992). Complex interaction of these factors makes it difficult to identify a potential cause for the lack of sprint improvements in both study groups. Although speculative, a potential factor related to the lack of improved sprint performance may be the reduced specificity of speed exercises during intervention, in addition to reduced technical skills or lack of proper sprint conditioning in their padel training program. Other reason could be that jumping exercises were non-specific to sprint performance and did not cause any effect on running speed (Fry, et al., 1991). When exercises were specific (e.g., speed bounding) to running performance, the training program had a positive effect on running velocity (Ford, et al., 1983). It is possible that a training program that incorporates greater horizontal acceleration (i.e., skipping, jumps with horizontal displacement) would result in the most beneficial effects (Sáez de Villarreal, et al., 2015).

Previous studies examined the influence of different types of training methods, including resistance training, plyometric and combined plyometric and resistance training on the development of COD performance (Asadi, 2013; Asadi, Arazi, Young, & Saez de Villarreal, 2016; Thomas, French, & Hayes, 2009; Váczi, Tollár, Meszler, Juhász, & Karsai, 2013). It has been previously reported that the combination of different neuromuscular exercises can influence the rate of adaptation and consequently greater improvements in COD performance (Arazi, Coetzee, & Asadi, 2012; Asadi, 2013; Váczi, et al., 2013), in line with our findings, showing COD improvements (2.5–4.9%, p<.05). Neuromuscular training may enhance athletes' ability to use the elastic and neuromuscular benefits of the stretch-shortening cycle (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Asadi, et al., 2016), in line with improved motor unit recruitment, thus COD (Aagaard, et al., 2002). Improvement in COD requires rapid force development and high-power output, and it seems that combined neuromuscular training can improve these requirements (Miller, Herniman, Ricard, Cheatham, & Michael, 2006; Sheppard & Young, 2006). In addition, the combined neuromuscular training may have improved the eccentric strength of the thigh muscles, a prevalent component in COD during the deceleration phase, decreasing ground reaction times through the increase in force output and movement efficiency, therefore positively affecting COD performance (Asadi, et al., 2016). Of note, the experimental group improved COD90R and COD180R. Handball players usually perform a high number of COD movements during regular handball-specific training and competition (Ortega-Becerra, Belloso-Vergara, & Pareja-Blanco, 2020), potentially decreasing the space for further improvement in COD ability. Therefore, the experimental training approach may have maximized this space in the non-dominant leg (i.e., the one with the "greater room" for improvement). If physiological changes (associated to COD performance) occurred to a greater level in the experimental group, particularly in the non-dominant leg (i.e., the left leg) including lower-limb power, rate of force development, maximal strength, speed, and reactive force (Brughelli, Cronin, Levin, & Chaouachi, 2008; Young & Farrow, 2006), these should be explored in future studies.

Some potentially relevant limitations of the study should be acknowledged. Firstly, although we included high-level padel players, the relatively reduced number of participants precluded generalization of the results. Secondly, in line with the first limitation, our findings may not be translated to other groups of padel players (e.g., females; youth; older athletes; low-level or recreative athletes). Thirdly, the lack of physiological and biomechanical measures precluded a comprehensive understanding of the changes observed during training. Future studies should aim to solve these potential limitations, particularly during longer-term interventions.

In conclusion, elite male padel players improved strength and specific padel skills such as jumping, SV and COD by undertaking an 8-week in-season combined neuromuscular training, consisting of strength, COD, and power-oriented exercises for both the upper and lower body.

Practical applications

We found that both training approaches were effective to improve padel players athletic performance. However, the integrated training approach induced greater improvements in padel-specific performance and was particularly effective to improve change of direction speed performance in actions involving the non-dominant leg (i.e., turns to the left). The performance improvements shown in this study are of great interest for padel coaches and are directly applicable to padel players. It is recommended that padel coaches implement during competitive season resistance and power-oriented training to enhance the performance of their players. The outcomes may help coaches and sport scientists formulate better guidelines and recommendations for athletes' assessment and selection, training prescription and monitoring as well as preparation for competition.

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Competing interests

None of the authors declares competing financial interests.