

Original Research

A six-week force-velocity profile based training is effective to optimize jump and change of direction performance in elite table tennis players

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Abstract: The aim of this study was to evaluate whether a specific training program based on the individual force-velocity (FV) profile would decrease the FVimb (i.e., difference between the players' actual and optimal profile) and, in turn, improve countermovement jump (CMJ) and change of direction (COD) performance. Nine elite table tennis players were assessed in two sessions for the FV profile, CMJ and COD. All players underwent a six-week specific resistance training program. The FVimb was significantly reduced ($ES = -1.37$; [95% confidence interval (CI) = -2.40 ; -0.35], $p < 0.05$), with moderate changes observed for the theoretical maximal force (i.e., F_0) ($ES = 1.09$; [95% CI = 0.10 ; 2.08], $p < 0.05$) and velocity (i.e., V_0) ($ES = -0.96$; [95% CI = -1.93 ; 0.02], $p < 0.05$). Conversely, the maximal power output (i.e., P_{max}) remained unchanged ($p = 0.52$). We also observed a significant CMJ enhancement ($+15.31\%$) and a better COD performance ($+5.09\%$). These findings suggest that assessing the FV profile might help coaches to individualize RT interventions. Specifically, increasing F_0 values during jumping could be associated with enhanced CMJ and COD performance in elite table tennis with a force-deficit.

Keywords: Strength; resistance training; speed; ballistic.

1. Introduction

Table tennis is a racket sport with an intermittent movement profile that comprises short rallies (~3,5 s), interspersed with longer resting times (between ~8 and 20 s) (Zagatto et al., 2016, 2018). Thus, success in table tennis relies on athletes' strength, speed, agility and fast decision taking to effectively stroke the ball (Bańkosz & Winiarski, 2018; Iino & Kojima, 2009, 2011).

These quick adaptations drive the players to make explosive change of direction (COD) movements with short accelerations and decelerations, requiring the lower limbs to perform quick footwork to achieve the best position, based on how the opponent hits the ball (Iino & Kojima, 2009, 2011; Lam et al., 2019; Qian et al., 2016; Zagatto et al., 2018).



From a performance perspective, players incorporate repetitive powerful forehand and backhand strokes with the goal of completing a point or hindering the opponent's stroke (Bańkosz & Winiarski, 2018; Iino & Kojima, 2009; Zagatto *et al.*, 2018). These efforts require a variety of footwork COD movements such as one-step, side-step, and cross-step based on rapid leg movements (Lam *et al.*, 2015, 2019; Qian *et al.*, 2016). In this regard, previous studies have investigated the kinetic and kinematic characteristics of different strokes, showing a stroke-specific lower limbs response. For instance, Zhang *et al.* (2013) observed greater vertical than horizontal ground reaction forces (GRF) during attacking strokes, usually accompanied with aggressive footwork movements (i.e., side-step and cross-step) (Lam *et al.*, 2019; Qian *et al.*, 2016; Zhang *et al.*, 2013). Interestingly, a synergy between the lower and upper limbs exists, whereby a transfer of momentum throughout the kinetic chain helps to accelerate the center of the mass, trunk and shoulders to efficiently transfer the force to the ball (Bańkosz & Winiarski, 2018; Iino & Kojima, 2009; Lam *et al.*, 2019). Therefore, identifying the best strategies to optimize footwork and COD performance should be of considerable interest for tennis table coaches and scientists.

Despite limited research on strength and conditioning in table tennis, some authors suggest that table tennis players demonstrate high recruitment and contractile capacities in the hip extensors, knee extensors, and plantar flexors during attacking strokes (Le Mansec *et al.*, 2018; Pradas *et al.*, 2010). Kaabi *et al.* (2021)

compared the effects of an 8-week training program involving weightlifting and plyometric exercises on countermovement jump (CMJ) and COD performance. While both conditions improved CMJ and COD performance compared to control group, weightlifting showed significantly greater gains. The force-velocity (FV) relationship has been proposed to assess lower limbs mechanical capacities in vertical jumping (Morin & Samozino, 2016). It characterizes the mechanical limits of the neuromuscular system to produce force (F_0), velocity (V_0) and maximal power output (P_{max}) (Samozino *et al.*, 2008, 2012). Each individual has an optimal FV slope, which balances F_0 and V_0 for maximum ballistic performance. Deviations from this optimal balance, known as FV imbalance (FVimb), can guide individualized training programs to improve ballistic performance (Samozino *et al.*, 2012). Experimental studies with soccer and rugby players have shown the effectiveness of an individualized FV profile training program to improve CMJ performance (Jiménez-Reyes *et al.*, 2017). Moreover, cross-sectional designs conducted by Baena-Raya *et al.* (Baena-Raya *et al.*, 2021) recently reported that F_0 and P_{max} are strongly associated with COD performance in tennis players. Together, these results suggest that optimizing the FV profile parameters might, in turn, result into COD enhancement (Baena-Raya *et al.*, 2021, 2022).

To date, no studies have examined the effects of a training program based on the FV profile on CMJ and COD performance in table tennis players. Such information would be of great interest for

coaches and strength and conditioning professionals for developing specific physical fitness components in table tennis players. Therefore, the aim of this study was to evaluate the effectiveness of a 6-week training program based on the FVimb to improve CMJ performance and COD performance in table tennis players. We hypothesized that improved CMJ performance would result from increasing F0 to reduce FVimb and shift the FV profile toward the optimal. Moreover, this reduction of FVimb would result into a COD enhancement due to a players' higher force capacity.

2. Materials and Methods

Subjects — Nine male elite table tennis players (age: 19.7 ± 3.7 years; height: 1.72 ± 0.09 body mass: 71.20 ± 6.61 kg) volunteered to participate in this study. All players played in high-level leagues across Europe as well as in major international events with their national teams. They practice between 3 to 6 hours per day in the practice hall, plus two hours per week of resistance training (RT), depending on the tournaments. None of the subjects exhibited any type of injury or limitation that might affect the tested performance. All subjects were informed of the risks and benefits of the study and gave their written consent before the initiation of the study. This study was reviewed and approved by the local ethics committee.

Design — We used a cross-over study design to investigate the effects of a 6-week individualized training program based on the FVimb on CMJ and COD performance. Two familiarization sessions were conducted the week before first data

collection, in which players performed several CMJ trials with different increasing loads as well as the COD test. The study was composed of three parts: Pre-test, training intervention, Post-test. The FV profile and COD testing procedures were performed before and after the training intervention. Since the nine participants showed a force-deficit, the training program was adjusted to reduce the FVimb through increasing F0, as previously suggested (Jiménez-Reyes et al., 2017). Players performed two sessions per week, separated by at least 48 hours of recovery. The participants continued with their practices and competitions and refrained from additional lower body training outside of our program. All training sessions were conducted in the same High-Performance Center.

Methodology — Prior to the tests, all players performed a standardized warm-up protocol including 5 min on a stationary bicycle at 60% of their self-perceived maximal intensity and 5 min of lower limb dynamic stretching. Then, they performed several trials of both unloaded and loaded CMJ before the FV profile test.

FV profile test — Participants performed maximal CMJ without external loads and against three external loads ranging from 10 to 70 kg. The heaviest external load (56.84 ± 10.52 kg) allowed each subject to jump approximately 12 cm (García-Ramos et al., 2018). The test was performed with a free-weight barbell. Two valid trials were performed with each load with 2 min of rest between trials and 4–5 min between loading conditions (Jiménez-Reyes et al., 2014; Samozino et al., 2012). Jump height was estimated from the flight time

recorded the OptoJump infrared platform (Microgate, Bolzano, Italy). Before each jump, participants were instructed to stand up straight keeping their hands on the bar. Thereafter, they squatted until a crouching position at a 90° knee angle, followed by a maximal vertical jump. The trials were checked by an experienced researcher, being repeated if these requirements were not met. Individual FV profile (F_0 , V_0 , FV slope, and P_{max}) were obtained following the simple method proposed by Samozino et al. (Samozino et al., 2008). The FV relationship parameters were determined through a linear regression model: $F(V) = F_0 - aV$, in which F_0 represents the force-intercept and a is the slope of the F-v relationship. The velocity-intercept ($V_0 = F_0/a$) and maximum power ($P_{max} = F_0 \cdot V_0/4$) were also calculated. Finally, the FV deficit was calculated as the percent difference between the optimal and the measured FV slope.

COD test — We used the Lateral Shuffle Test to assess COD performance in table tennis players. McCormick et al. (McCormick, 2014) proved the validity and reliability of this test to measure lateral COD movements. Participants performed 2 submaximal trials and recovered for 3 minutes before the beginning of the test. The distance was marked at 8 feet (2.44m) in length with lines marked every two feet (60.96cm) (Figure 1). The participants' score was the number of lines crossed during the test (10 s). A video camera was used to capture the trials and to confirm the score via video analysis. The time started on the participants' first visible movement. They started in a base position. On the researcher's verbal signal, the participants

started the lateral shuffle to the left side. They changed directions when the outside leg crossed the outside line (McCormick, 2014). If the participant crossed their legs, the test was not valid. If these conditions were not met, the test was repeated. Two trials were recorded for every participant.

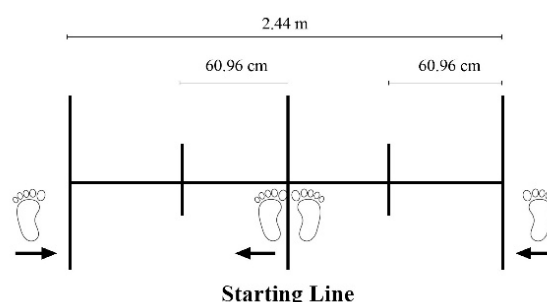


Figure 1. Schematic representation of the Lateral Shuffle Test.

Training intervention — During the 6 weeks of training, players performed a force-oriented training with two “strength” exercises (back squat and deadlift) and one “strength-power” exercise (CMJ). The descriptive characteristics of the training program are shown in Tables 1 and 2. Training intervention was organized following previous recommendations from the literature to optimize neuromuscular performance: 2-3 sessions per week, lowering the volume (from 8 to 3 repetitions), increasing the intensity (i.e., closer to the one-repetition maximum (1RM)) from 60 to 80% 1RM (Suchomel et al., 2021), and lifting at the maximal intended velocity during the concentric phase of the exercise (Pareja-Blanco et al., 2014). To better understand the incurred level of fatigue, RT exercises (squat and deadlift) were monitored through the level of effort, which is a reliable and practical alternative to the velocity-based approach (Hernández-

Belmonte et al., 2021; Morán-Navarro et al., 2019; Suchomel et al., 2021). Briefly, this methodology configures the actual number of repetitions performed in each set, which determines the incurred fatigue (i.e., velocity loss (VL)) in relation to the maximum number that can be completed (which is directly associated with the relative load (i.e., %1RM) (Hernández-Belmonte et al., 2021; Morán-Navarro et al., 2019). Participants had at least one year of experience in squatting and deadlifting as well as using the level of effort as part of their in-season exercise routine. To warm-up, participants performed 5 minutes on a stationary bicycle at 60% of their self-perceived intensity, 5 min of lower limb dynamic stretching, followed by 10 back squats and deadlifts with a 20 kg bar. Then, they performed 3 repetitions with the 50% of the proposed load for the training session. The absolute load (kg) was daily adjusted in function of the players' readiness. All training sessions were conducted in the same High-Performance Center.

Statistical Analysis— Descriptive data are presented as means and standard deviations. Prior to any statistical analysis, we assessed the distribution of the main variables using the Shapiro-Wilk test. In view of the non-normally distributed data, a non-parametric test (Wilcoxon Signed Ranks test), with a level of significance of $p \leq 0.05$ was used to investigate a possible significant change in the means, comparing the pre-post values of the FV profile variables, CMJ height and COD performance. The magnitude of the changes was assessed using Hedge's g (ES, 95% confidence interval), which was interpreted

by using values of trivial (< 0.20), small (0.20 to < 0.60), moderate (0.60 to < 1.20), large (1.20 to < 2.00), and extremely large (> 2.00) (Hopkins et al., 2009). The qualitative probabilities are defined by the following scale: almost certainly not, $< 0.5\%$; very unlikely, $< 5\%$; possible, 25-74.9%; likely, 75-94.9%; very likely, 95-99.5%; and most (extremely) likely $> 99.5\%$ (Hopkins et al., 2009). All the statistical analyses were performed using SPSS version 25.0 (SPSS, Chicago, IL).

3. Results

Mean $\pm$ SD values for all performance and mechanical variables pre and post training intervention are shown in Table 3. Moderate changes were observed for F0 (ES = 1.09; $p < 0.05$) and V0 (ES = -0.96; $p < 0.05$), resulting in a significant decrease in the FVimb from 43.44% to 23.11%. This indicates that players significantly reduced their initial force deficit (ES = -1.37; $p < 0.05$). Conversely, Pmax showed a small increase (ES = 0.26) that did not reach a significant change ($p = 0.052$). The modulation of the FV profile resulted in a significant CMJ enhancement (+15.31%) and a better COD performance (+5.09%) (Figure 2).

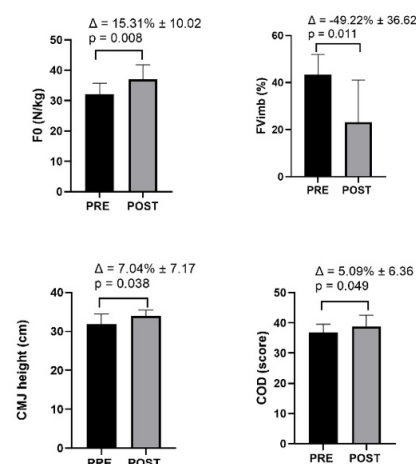


Figure 2. Strongest Pre-Post changes in the FV profile mechanical variables, CMJ and COD performance.

Table 1. Descriptive characteristics of the resistance training program.

Week	Sets	Level of Effort	Load (%1RM)	Inter-set rest (min)
1	3	8(22)	~60%	3
2	3	6(19)	~65%	3
3	3	5(15)	~70%	3
4	4	4(11)	~75%	3
5	4	4(11)	~75%	3
6	3	3(9)	~80%	3

Number outside the parenthesis: number of repetitions completed. Number in parenthesis: nRM that could be completed at the specific %1RM.

Table 2. Descriptive characteristics of the strength-power training program.

Countermovement jump			
Week	Sets x reps	Load (% BW)	Inter-set rest (min)
1	3 x 8	20%	3
2	3 x 6	25%	3
3	3 x 5	30%	3
4	4 x 5	35%	3
5	4 x 4	40%	3
6	3 x 4	40%	3

Reps, repetitions; BW, body weight.

Table 3. Changes in variables associated to force-velocity profile, countermovement jump height and change of direction performance.

Variables	Mean ± SD		p-value	ES (95% CI)	Qualitative Probabilities (%)
	Pre	Post			Positive/Trivial/Negative
CMJ Height (m)	0.32 ± 0.03	0.34 ± 0.02	0.038	0.75 (-0.21 ; 1.70)	98/3/0
F0 (N/Kg)	32.12 ± 3.66	36.99 ± 4.80	0.008	1.09 (0.10 ; 2.08)	94/5/1
V0 (m/s)	3.52 ± 0.39	3.08 ± 0.48	0.028	-0.96 (-1.93 ; 0.02)	0/2/98
Pmax (W/Kg)	27.50 ± 1.91	28.03 ± 1.98	0.515	0.26 (-0.67 ; 1.19)	54/28/17
FV _{IMB} (%)	43.44 ± 8.53	23.11 ± 18.01	0.011	-1.37 (-2.40 ; -0.35)	0/0/100
COD (score)	36.89 ± 2.67	38.78 ± 3.77	0.049	0.64 (-0.39 ; 1.49)	93/6/1

CMJ, Countermovement jump; ES, Effect size; SD, Standard deviation; CI, confidence intervals; F0, Theoretical maximal force; FV_{IMB}, Force-velocity imbalance; LST, Lateral Shuffle Test; Pmax, maximal power output; V0, Theoretical maximal velocity.

4. Discussion

This study was designed to evaluate the effectiveness of a 6-week training program based on the FVimb to improve CMJ and COD performance. The main findings of this study indicates that the 6-week RT program was effective to reduce the force-deficit in elite table tennis players. Additionally, the increase in F0 was also accompanied by improvements in both CMJ

and COD performance. Therefore, these results suggest that a RT program based on the FV profile might increase ballistic performance in elite table tennis players.

Jumping performance relies on the players’ ability to accelerate their body as much as possible within the shortest time possible, which determines the mechanical impulse produced onto the ground (Jiménez-Reyes et al., 2014; Morin &

Samozino, 2016). Interestingly, the FV relationship allow coaches to individually determine whether their players have a force or velocity deficit to target training program and, consequently, maximize performance (Samozino *et al.*, 2012). As firstly hypothesized, the proposed RT program significantly increased F0 and CMJ performance, while the FVimb decreased (Table 3). These results concur with previous training interventions tailored to reduce the force deficit in jumping that also reported a large reduction in FVimb ($ES = -1.60 \pm 0.26$) and a large positive change in both F0 ($ES = 1.60 \pm 0.17$) and CMJ height ($ES = 1.00 \pm 0.17$) for soccer and rugby players (Jiménez-Reyes *et al.*, 2017). Similarly, despite the significant reduction in FVimb, these authors also reported no change in Pmax ($ES = -0.04 \pm 0.17$), which concurs with the small changes observed in the current study (Table 3). Importantly, the significant increases in CMJ height reported in both studies (+15.31% and +14.2%) support that not only the Pmax should be considered to maximize CMJ performance, but also the individual FV profile (Jiménez-Reyes *et al.*, 2017; Morin & Samozino, 2016; Samozino *et al.*, 2012). Of note, lower limbs' explosive strength plays a key role to perform rapid shots in table tennis (Le Mansec *et al.*, 2018; Pradas *et al.*, 2010). Therefore, improving neuromuscular performance through a FV profile optimization might significantly affect table tennis performance.

The main tactical goals to win a match in table tennis are based on producing high racket speed to perform a fast stroke (Báńkosz & Winiarski, 2018; Iino & Kojima, 2009). In fact, it is known that a higher racket speed results in a higher post-impact ball speed and ball spin, which aggravate the opponent's offensive stroke (Iino & Kojima, 2011; Lam *et al.*, 2019; Le Mansec *et al.*, 2018). Importantly, lower limbs' biomechanics also determine upper limb performance in table tennis, which indicates the existence of a

synergy between both extremities. Thus, higher skilled players seem to exhibit faster trunk and shoulder rotations through a better use of their ankle, knee, and hip joints (Báńkosz & Winiarski, 2018; Iino & Kojima, 2009, 2011). This is especially relevant during side-step movements such as the COD assessed in the present study, which requires greater vertical GRF and plantar pressure than one-step footwork (Brown *et al.*, 2014; Lam *et al.*, 2019; Zhang *et al.*, 2013). In this regard, our current results showed the effectiveness of a six-week RT program to improve the mechanical capacities of lower-body muscles to produce force in the vertical direction (*i.e.*, F0) (Table 3). Accordingly, it might be assumed that a greater ground force application may result in a better transfer of kinetic energy from lower to upper limbs, which could allow players to generate higher racket and ball speed.

While most published analysis of table tennis have examined the kinetics and kinematics of different strokes, the evidence regarding the effects of RT on sports-specific movements such as the side-step is still very limited. However, in the present study we assessed whether a training intervention tailored to improve the players' force capacity would result into a COD enhancement as well. Notably, we observed a significant increase in COD performance (+5.09%) (Figure 2). Although previous studies suggest that a good footwork may contribute to a better hitting performance and that it can be optimized through frequent repetitions of the stroke (Báńkosz & Winiarski, 2018), the current results suggest the potential influence of developing force capacity in table tennis players to also improve COD actions. This might be advantageous for table tennis performance and injury prevention since players perform brief explosive movements to quickly change of direction to hit the ball (Le Mansec *et al.*, 2018). Specifically, sidestepping

requires neuromotor control to perform aggressive accelerations and decelerations, increasing knee loading and the tension of the viscoelastic tissues (Brown et al., 2014; Dos'Santos et al., 2018; Lam et al., 2015, 2019). Thus, increasing force capacity may be especially relevant in table tennis players to improve the weight acceptance during the braking phase, which allows them to push-off faster in the new direction (Brown et al., 2014; Dos'Santos et al., 2018).

Despite the contributions of this study, several limitations must be addressed. A major limitation is the lack of a control group, which may restrict the strength of the conclusions. Although this is the first study to suggest a RT program based on the FV profile for table tennis players, the absence of a control group prevents establishing a clear cause-and-effect relationship between the RT program and improvements in CMJ and COD performance. Secondly, further experimental research with more training conditions (e.g., plyometric training) is needed to determine which intervention is more effective to improve COD performance. Moreover, as it was difficult to recruit a large sample of elite table tennis players, our sample size was relatively small and future research with larger sample size is warranted.

5. Practical Applications.

A six-week training intervention based on squats, deadlifts and loaded CMJ jumps increased F0 and reduced the FVimb in elite table tennis players with a force-deficit. This shift in player's FV profile was accompanied with a significant COD and CMJ enhancement in elite table tennis players. Therefore, our findings suggest that a RT program based on the FV profile might increase ballistic performance in elite table tennis players.

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Conflicts of Interest: The authors declare no conflict of interest.

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