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UNIVERSIDADE DO PORTO

Force-Velocity Profile Analysis Following a 6-Week Specific Training Program and Its Implications on Change of Direction in Elite Table Tennis Players

Dissertation presented with a view to obtain the 2nd cycle in Sports Training, specialization in High Performance, from the Faculty of Sports of the University of Porto, under the Decree-Law No. 74/2006, of March 24th, in the writing given by Decree-Law No. 65/2018 of August 16th.

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Porto, 2021

Catalogation sheet

Neves, J. D. L., (2021). Force-Velocity Profile Analysis Following a 6-Week Specific Training Program And Its Implications on Change of Direction in Elite Table Tennis Players. Oporto: J. Neves. Dissertation with a view to obtain a Master's degree in Sports Training in High Performance branch, presented to the Faculty of Sports of the University of Porto.

Key-words: TABLE TENNIS; VERTICAL JUMP; FORCE-VELOCITY PROFILE; CHANGE OF DIRECTION; TRAINING PROGRAM.

Acknowledgments

First, I would like to thank my Professor and Advisor Filipe Conceição, for the availability since day one, with a motivating energy towards what was then just an idea being born. This study would not be the same without his knowledge and calm towards all the adversities we encountered.

Second, I would like to thank Andrés Baena Raya, for his enormous contribution and knowledge to this study. Without his help, everything would be a lot more difficult to accomplish. His ideas were a key element to help me go the right way.

To the director, coaches and athletes of the High Performance Center in Vila Nova de Gaia, I also must thank for the availability and motivation that they showed when I presented this project to them.

To my family, I would like to thank for all the patience and help they always showed. Without their support, these five years following my dreams would not be possible.

To my friends, who helped me when I asked, called me when I didn’t ask, and made my journey so good through these years, thank you.

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Abtract

The main goal of this study was to investigate the effects of a six week-long training program on the Force-Velocity profile of elite table tennis players. The specific goal was to investigate if the training program, focused on improving vertical jump height, influenced Change of Direction performance.

The sample consisted of 9 male table tennis players, that represented their national teams (youth and/or senior). All the players practiced in the High-Performance Center in Vila Nova de Gaia.

The Force-Velocity profiles of the players were assessed with the MyJump app, before and after the training program. For the Change of Direction performance, the Lateral Shuffle test was used.

To analyze a possible change, when comparing the pre and post training program values, the results were subjected to a non-parametric repeated measures test, with a significance level set at $p \leq 0.05$. Effect size standard changes were also calculated.

The results show a significant improvement on the Countermovement jump height (0,32(0,03) m to 0,34(0,02) m). The imbalance between the actual and optimal Force-Velocity profiles of the participants decreased significantly (43,44(8,53) % to 23,11(18,01) %), resulting on more balanced profiles. The F0 values increased significantly (32,12(3,66) N/Kg to 36,99(4,80) N/Kg), while the V0 values decreased (3,52(0,39) m/s to 3,08(0,48) m/s). The Pmax values did not present a significant change. Regarding the Lateral Shuffle test, the scores increased significantly from 36,89(2,67) to 38,78(3,77), which represents a 5,12 % improvement in COD performance.

We concluded that this training program had a positive effect on jumping performance capabilities (i.e., enhanced jump height and mechanical variables of the Force-velocity profile) that was also translated into an enhanced COD performance. These results suggest a potential relationship between the athletes' neuromuscular ability to apply force during vertical jumping and COD performance. Therefore, considering the importance of explosive movements and changes of direction on table tennis competition, these results will likely help coaches to prescribe training programs.

Key-words: Table Tennis; Vertical jump; Force-Velocity profiles; Change of Direction; Training Program.

Resumo

O objetivo principal deste estudo foi investigar os efeitos de um plano de treino, com a duração de 6 semanas, focado no perfil Força-Velocidade de atletas de elite de ténis de mesa. O objetivo especifico foi investigar se este plano de treino, que tinha como foco melhorar a impulsão vertical, vai influenciar a performance na Mudança de Direção.

A amostra é constituida por 9 atletas masculinos de ténis de mesa, que representaram as suas seleções nacionais (escalões jovens ou séniores). Todos treinam no Centro de Alto Rendimento de Vila Nova de Gaia.

Os perfis Força-Velocidade foram obtidos através da aplicação *MyJump*, antes e depois de aplicar o plano de treino. Para avaliar a Mudança de Direção, foi utilizado o *Lateral Shuffle Test*.

Para analizar possíveis alterações, quando comparando os resultados antes, e depois do plano de treino, os resultados foram sujeitos a um teste não-paramétrico de medidas repetidas, com o nível de significância a $p \leq 0.05$. Também foi feito o teste de *Effect size standard changes*.

Os resultados apresentam uma melhoria significativa na altura do *Countermovement jump* (0,32(0,03) m para 0,34(0,02) m). O desequilíbrio entre o perfil Força-Velocidade real e o optimal diminuiu significativamente (43,44(8,53) % to 23,11(18,01) %), resultando em perfis mais equilibrados. Os valores de F0 aumentaram significativamente (32,12(3,66) N/Kg to 36,99(4,80) N/Kg), enquanto que os valores de V0 diminuiram (3,52(0,39) m/s to 3,08(0,48) m/s). Os valores de Pmax não apresentaram alterações significativas. Em relação ao *Lateral Shuffle Test,* os resultados apresentam um aumento significativo de 36,89(2,67) para 38,78(3,77), que representa um aumento de 5,12% na performance da Mudança de Direção.

Concluimos que o plano de treino teve um efeito positivo na impulsão vertical (ex. Melhorias nos valores de salto vertical e nas variáveis mecânicas dos perfis Força-Velocidade) que também transferiu para uma melhor performance na Mudança de Direção. Estes resultados sugerem uma potencial relação entre as habilidades neuromusculares que os atletas têm de aplicar força num salto vertical, e a sua performance na Mudança de Direção. Assim, considerando a importância dos movimentos explosivos e das mudanças de direção no ténis de mesa, estes resultados provavelmente ajudarão os treinadores a prescrever e planear os treinos.

Palavras-chave: Ténis de Mesa; Salto Vertical; Perfil Força-Velocidade; Mudança de Direção; Plano de Treino.

List of Abreviations

CMJ – Countermovement Jump

COD – Change of Direction

F/V_{IMB} – Force-Velocity Imbalance

F0 - maximum theoretical force

F-V Profile – Force-Velocity Profile

hmax – maximal jump height

hPO – Push-Off Distance

LST – Lateral Shuffle Test

Pmax - maximum power

V0 - maximum theoretical velocity

Introduction

Due to the world pandemic that we are currently going through (SARS-CoV-2), finding a reliable and valid way to measure and analyze important performance parameters, such as power outputs or force and velocity values, on the field, is very important. Finding a way to be able to monitor the athletes' performance without the necessity of a fully equipped laboratory, or displacing the athletes from their usual practice zone, gains more relevance than ever. As such, Samozino et al., developed in 2008 a field method, based on the fundamental laws of mechanics, that "proposes an accurate and reproducible simple field method to evaluate the power output of lower limbs' extensor muscles with a precision similar to that obtained with specific laboratory ergometers". During the following years, different studies confirmed this method as a valid and reliable way to measure neuromuscular capabilities, such as force, velocity and power outputs, relying only on squat jumps and easily measurable parameters: body mass, jump height and push-off distance (Samozino et al., 2010; Giroux et al., 2014; Jiménez-Reyes et al., 2017).

Summarized through force, power and velocity outputs, this simple field method, allow coaches to trace neuromuscular performance during the seas and also to detect potential deficits in their individual FV profile (i.e., the difference between the actual and the optimal FV profile) (Samozino et al., 2012). Thus, ballistic performance depends not only on maximum power, but also on the imbalance presented between the real and the optimal profiles of the subjects (FVIMB) (Samozino et al., 2013; Morin & Samozino, 2016; Jiménez-Reyes et al., 2014, 2017). Interestingly, Balsalobre-Fernández et al., (2014) recently showed the validity and reliability of an iPhone app (My Jump) to measure jump height during Counter Movement Jump, which allow coaches to monitor jumping performance in real sport settings only by recording the jump.

Table tennis players need to perform short and explosive lower extremity movements, that are essential to achieve the right position to hit the ball (Pradas et al., 2011). These movements are mainly lateral and require frequent changes of direction.

Change of Direction (COD) tests have used mainly straight running and sprints, with almost no information concerning lateral movements. This led McCornick (2014) to study the consistence, reliability and validity of a Lateral Shuffle Test. This test differs from other COD tests, since it is concerned only with lateral movements (lateral shuffle). After analyzing four different variations of the Lateral Shuffle Test (LST), the results indicated "that the LTS is a reliable and valid measure of CODS", with "a distance of 8 feet (2.44 m) and a time of 6 seconds or 10 seconds are the most reliable".

The aim of this study was to investigate the effects of the application of a six week-long training program on the Force-Velocity profile of elite table tennis players. Counter Movement Jumps were used to trace the Force-Velocity profiles. This led to the secondary goal of this study: investigating a possible influence of jump height on the table tennis specific movements. A Change of Direction test was used, aiming to measure the table tennis specific movements' performance.

Initially, this work presents a review of the current state of the art on the area and subjects being studied. This literature review considers the studies carried out in strength and conditioning in sports, focusing on finding a valid and reliable field test to measure and analyze important performance parameters.

The main and secondary goals are presented, followed by the hypotheses.

Then, the methods and procedures are introduced. This section describes the sample of the study, the variables, the different tests and methods used, as well as the statistical procedures.

Finally in the last section, the results and the discussion are presented, and compared to the literature already established, in an attempt to get new information on this field of studies.

Literature Review

F-V Profile

“Jumping performance represents the typical example of ballistic movements, and such movements (i.e., jumping, start sprinting, changing of direction, etc.,) are some of the keys of performance in numerous sport activities” (Jiménez-Reyes et al., 2014, p. 8). Measuring performance parameters usually requires specific devices and equipment, or a fully equipped laboratory. Therefore, accurate field methods are an area of study in development that gains an increasing interest for coaches and researchers, in order to proper evaluate athletes and set up the best and specific plans to improve athletes’ performance. This way, Samozino et al. (2008) studied a method to “evaluate the power output of lower limbs’ extensor muscles with a precision similar to that obtained with specific laboratory ergometers”. In this study, they used the fundamental laws of mechanics, to explain how parameters like Force and Velocity affect the power output, in squat jump movements. Only needing body mass, jump height, loads, , and 3-5 squat jump and an computer/excel or mobile application, a very useful field method can be generated. Giroux et al. (2014), found this method reliable and valid to assess force, velocity and power measurements, while comparing it to different methods, including force plates.

With the aim to identify what parameters are limiting the jumping performance, Samozino et al. (2010), attempted to identify the mechanical factors that determine jumping ability quantifying their influence. Through a mathematical approach, they found possible to express “the maximal jump height an individual can reach (hMax) as a function of only three mechanical entities that represent overall mechanical characteristics of lower extremities: The theoretical maximal extremities extension (F0), the theoretical maximal velocity at which the lower extremities can extend under the influence of muscles contraction in unloaded conditions (V0), and the extension range of the lower extremities determining the distance over which force can be generated (hPO)” (Samozino et al. 2010, p 15). In conclusion, this study found a way to express the maximal height an individual can jump, from their extension range, their maximal force production and extension velocity, which are mechanical parameters easily measured using the method developed by Samozino et al. (2008).

These findings were of great interest, as it was possible to find a relation between the force and velocity values, tracing the individual's F-V optimal profile. This optimal profile, related to the best balance between force and velocity capabilities, depends on the limb extension range, the maximal power outputs (Pmax) and the afterload involved in the jump. This was studied by Samozino et al. (2012), where they hypothesized that ballistic performance is not only determined by the Pmax values, but also by the F-V profile, which could be manipulated to optimize jumping performance. This theory was confirmed then by different studies, where they concluded that not only increasing Pmax would increase jumping ability, but also decreasing the F/V_{IMB}, which is the deficit between the optimal F-V profile traced for the individual and his real F-V profile. (Samozino et al., 2013,2016; Jiménez-Reyes et al., 2014; Morin & Samozino, 2016).

The F-V profile for the Squat Jump (SJ) has been studied and proven its importance in jumping performance. In training and competitions, the athletes usually perform ballistic movements that include both concentric and eccentric phases, closer to the Counter Movement Jump. That said, the F-V profile for the CMJ was tested by Jiménez-Reyes et al. (2014). When comparing the F-V profiles in SJ with the CMJ, the results showed that while still linear, the F0 and V0 values were significantly higher in CMJ. As in SJ, the CMJ performance depends not only on Pmax, but also on the F/V_{IMB}. Jiménez-Reyes et al. (2017), determined this method as a valid way to assess the F-v profile with CMJ, and for evaluating force, velocity and power output, in elite athletes.

To decrease the F/V_{IMB}, the training has to be focused on what kind of imbalance the individual presents (Samozino et al. 2016, Jiménez-Reyes et al. 2017, Álvarez et al. 2020). Results have demonstrated that individualized training, with individuals that show a force deficit, going through a force orientated training, or velocity deficit individuals through a velocity orientated training plan would improve jump performance.

Balsalobre-Fernández et al. (2014) analyzed the validity and reliability of an iPhone app to measure CMJ height. They concluded that this app was valid and reliable, with results close to force platforms, considered as the gold standard for vertical jump measurements (Glatthorn et al., 2011; Requena et al. 2012; Sayerset al., 1999 cit. by Balsalobre-Fernández et al., 2014 p. 1). These results "could help coaches (…) who wish to monitor the vertical jump ability of their athletes or clients in a valid and economic way" (Balsalobre-Fernández et al., 2014 p. 7).

CoD

Change of direction (COD) is an ability that seems to be influenced by different factors, such as technique, the COD angle biomechanics, and lower limb muscle activity. (Dos'Santos 2017, 2018, 2020; Pauole et al. 2000). This ability, to maintain a good control of the body during a quick change of direction, is essential in different sports' movements and moments (Miller et al. 2006; Pauole et al. 2000; Raya et al. 2013). Reliable and valid tests to measure different ways of COD becomes relevant to coaches, trying to improve their athlete's performance in this movements (Dos'Santos et al. 2018; Raya et al. 2013; Pauole et al. 2000).

Pauole et al. (2000), while testing the reliability and validity of the T-Test, showed results that suggest this test relates more to leg speed than leg power and agility. Nonetheless, they affirm that the selection of a field test for a sport activity should focus on the specificity of the activity in question. Miller et al. (2006), studied the effects of a plyometric training program on agility. Using the T-Test as the test of agility, results indicate that plyometric training improves the times registered in this agility test. It is hypothesized that the eccentric-concentric actions of the muscles that are present in the plyometric exercises may be similar to the agility test's movements, resulting in adaptations that may improve the efficiency on the change of direction.

Dos'Santos et al. (2017), analyzing the mechanical determinants of the COD speed performance, identify this eccentric-concentric action and the rapid application of force as important elements in the COD movements. They suggested the plyometric training to develop the lower limb strength and rate of force development (RFD). Later in 2018, Dos'Santos et al. (2018) corroborate these findings. Their results show that plyometric training is important for faster COD performance, highlighting the importance of this exercises being performed in several directions. To improve COD performance, coaches must have in mind the biomechanical research on the technique, and the physical demands of the COD movements, in order to plan a suitable training program, which may include plyometric exercises.

Raya et al. (2013), compared three different agility tests, the Edgreen Side-Step Test, the T-Test and the Illinois Agility Test. The results showed that the three tests appear reliable and may help coaches to plan specific goals considering the different sport activities. The Edgreen Side-Step test is unique, with only lateral movements. Being unique in this specificity, only lateral movement, this type of test for the evaluation of change of direction, free of straight running prompt McCormick (2014) to investigate it. With an inconsistent application of the Edgreen Side-Step Test on the literature, this study tried to establish a consistent, reliable and valid Lateral Shuffle Test (LST), proposing four conditions that combined two different times and distances. The results showed good consistency and test-retest reliability for the conditions used. The 8 feet (2,44 m) and 6 or 10 seconds time variations were found to be the most valid and reliable combinations to measure COD. The LST, with only lateral movements, consists on specific movements typical of some sports, for example the movements used in defensive actions in basketball.

Table Tennis

Zagatto et al. (2018), when studying the characteristics of table tennis competition, described table tennis as a racked sport with an intermittent movement profile, considering that the rallies are relatively short, around 3,5 seconds, with longer resting times, between 8 and 20 seconds. When playing, table tennis players need to apply various skills: speed, strength, agility, endurance, decision taking, in order to quickly adapt to the continuously changing conditions to effectively stroke the ball (Pradas et al. 2011; Faber et al. 2015; Le Mansec et al. 2017, 2018). These quick adaptations drive the players to make short and explosive change of direction movements, requiring the lower limbs to perform quick footwork to reach the best position, based on how the opponent hit the ball (Pradas et al. 2010, 2011; Le Mansec et al. 2017, 2018, Lam et al. 2019).

Pradas et al. (2011), while analyzing the jumping force manifestation in table tennis, showed that table tennis players have a good strenght-velocity relationship, essential to the game, namely the high recruitment and contractile capacities as the predominant strength expressions. They concluded that explosive strength is the most important manifestation on this sport, resulting in the high-speed movements performed to reach an ideal position.

Zhang et al. (2013), with a different approach, tried to understand the lower limbs' force in table tennis by studying the Ground Reaction Force (GRF) of the athletes in two different strokes. They observed that, in attacking strokes, the vertical GRF were more predominant than the horizontal GRF, since the forces were applied vertically on the ground , while the drive technique demonstrated a higher horizontal GRF, with more consideration on the lateral and posterior-anterior directions. This showed that different strokes require different lower limbs response. Lam et al. (2019), besides the GRF, examined the knee and ankle moments, as well as an in-shoe plantar pressure distribution, during three table tennis specific footwork movements. Their results show different GRF values, depending on the type of movement performed. The more aggressive footwork movements (side-step and cross-step), also demonstrated higher peak plantar pressure.

Recently, Le Mansec et al. (2017), analyzed the Neuromuscular fatigue during a table tennis competition. By simulating a competition, with time motion analyses and different neuromuscular tests (Force measures, Electromyography, Electrical stimulation), they demonstrated that most actions in table tennis are performed at a low and moderate intensity, with a smaller portion in a high intensity actions that included decisive and more aggressive strokes. The actions during competition resulted on significant force loss in a maximal voluntary contraction test, when compared to the one made before the competition. Due to the intermittent profile of table tennis, the ability to repeat high intensity actions is believed to be an important element to performance, with the contribution of the lower limbs present on the explosive nature of the table tennis movements. Following this study, Le Mansec et al. (2018) studied the lower limb activity during seven table tennis strokes. The more aggressive strokes demonstrated higher lower limb muscles activation, with not only the knee extensors, but also the hip extensors and plantar flexors being strongly activated during decisive strokes.

Concerning Counter Movement Jump and Change of Direction, Kaabi et al. (2021) compared Weightlifting and Plyometric training. Even though there is not much strength and conditioning research on table tennis, this study implemented 8-week training plan on table tennis players, divided by 3 different groups: a control, a weightlifting, and a plyometric training group. Considering how important explosive force and change of direction is on table tennis performance, they used the CMJ test and the T-Test, to understand the impact of the training. The results show that both variations (weightlifting and plyometric training) improved the COD T-Test results, and the CMJ results. Between them, only the CMJ results were significantly higher in the Weightlifting group, comparing to the Plyometric training group. This way, to improve the physical characteristics known to be important for table tennis performance, both weightlifting and plyometric exercises are recommended.

Goals and hypothesis

Main goal

To investigate the effects of a six week-long training program, on the Force-Velocity profile and jump height of elite table tennis players.

Specific goals

To investigate if Change of Direction results alters, following a training program focused on vertical jump height.

Hypotheses

Hypothesis 1: The participants F-V profiles imbalance reduces and jump height improves, after the training program application.

Hypothesis 2: The Change of Direction results change after the training program application.

Methods and Procedures

Sample characterization and selection criteria

The sample for this study consisted of 9 elite table tennis players, practicing in the High-Performance Center in Vila Nova de Gaia. The criteria used to select the participants was: male players, with National Teams participations (youth and/or senior). All the participants play in high level leagues across Europe: France, Germany, Spain and the Portuguese 1st division. Some even play major international events representing their home countries.

The sample, with a mean age of 19,7 (3,7) years old, was composed of players from different nationalities, Portuguese, French, and Argentine. They usually practice between 3 to 6 hours a day in the practice hall, and complement that practice with 2 hours a week of physical training, depending on the competitions and league matches. Table 1 describes the sample diversity and characteristics.

Participant	National team participation	Nationality	Leagues played
1	Youth	French	Spain – 1^{st} division and France 3^{rd} division
2	Youth	Portuguese	Portugal - 1^{st} division
3	Youth and Senior	Argentine	Germany – 2^{nd} division
4	Youth	Portuguese	Portugal - 1^{st} division
5	Youth	Portuguese	Portugal - 1^{st} division
6	Youth	Portuguese	Portugal - 1^{st} division
7	Youth	Portuguese	Portugal - 1^{st} division
8	Youth	Portuguese	Portugal - 1^{st} division and Spain 1^{st} division

9	Youth and Senior	Argentine	France – 2nd division

Table 1 – Participants' characterization

Since each participant has a different event calendar, and there are competitions all year round, there is not a single "off-season" time to focus more on the physical work, so this study was planned considering avoidance of any harm to the participants during their competition phase.

All the participants voluntarily signed a declaration of consent, where all the methods, procedures and study goals were explained. By signing this declaration, they showed their availability to participate in this study in accordance to the Declaration of Helsinki by the World Medical Association (Attachment A).

Variables

In this study, the variables used consist in the participants anthropometric data and the F-V profile data. The anthropometric data consisted in the participants weight, the length of the lower limb in a lying position, with a plantar flexion, and the distance from the floor to the right great trochanter, with the knees in a 90º angle flexion. The F-V profile data involved the hPO (consisting in the difference between the two measures referred above), the F/V imbalance, F0, V0, hmax and the Pmax values.

One more variable on this study is the LST results collected.

Anthropometric Data Collection

There were two moments for the anthropometric data collection, following the two moments of evaluation. The first data collection took place between February 28th and March 13th, and the final data collection took place between April 25th and May 8th, so that each participant completed the 6 weeks of the training program. For each participant, the distance between the great trochanter and the toe of the lower right limb, with the foot in plantar flexion, in a lying position was measured using a measuring tape. Then, in a squatting position, with the knees on a 90º angle, the vertical distance between the ground and the great trochanter was measured.

Following Samozino et al., 2014, the difference between these two measures (great trochanter – toe and great trochanter – ground) determines the hPO. Weight was also collected. Both measurements are described in table 2.

Participant	Weight (Kg)	hPO (m)
1	83.3	0.36
2	73.8	0.34
3	65	0.32
4	77.8	0.31
5	74.7	0.33
6	65.3	0.26
7	65.4	0.32
8	65.5	0.24
9	70	0.33

Table 2 - Weight and hPO measurements

Instruments

The players' weight was measured using a scale. To determine the hPO, a measuring tape was used to measure 2 distances: (i) the distance between the great trochanter and the toe of the lower right limb, with the foot in plantar flexion, in a lying position; (ii) the vertical distance between the ground and the great trochanter in a squatting position (knees on a 90º angle). The difference between the 2 distances determines the hPO. Figure 1 shows the hPO measuring process, following Jiménez-Reyes et al. (2017).

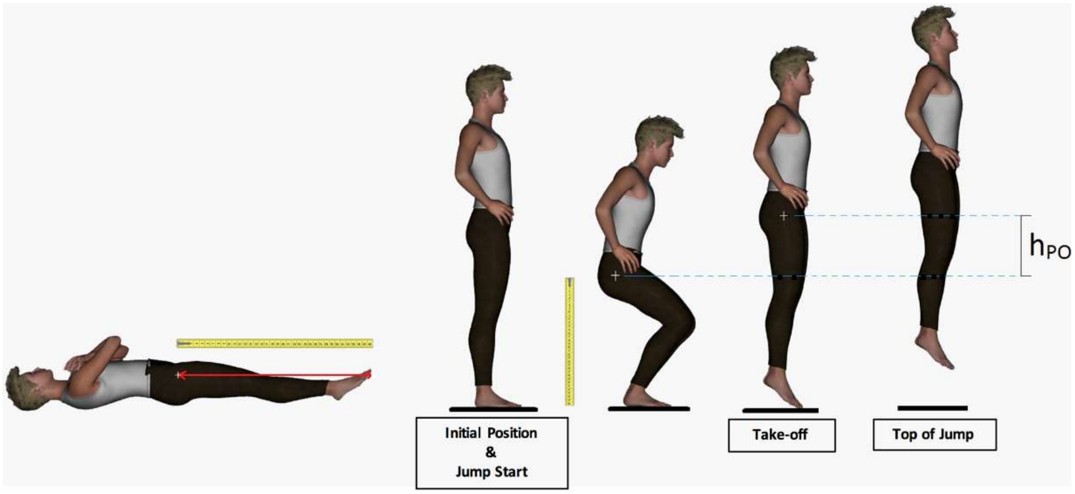

Figure 1 - hPO measurement (in Jiménez-Reyes et al., 2017, p. 38)

To measure the CMJ height, the MyJump app was used with a Xiaomi Pocophone F1 device.

Concerning the COD, the Lateral Shuffle test was used. This test is set with 5 markers on the ground. The markers are at a 0,61 m distance from each other, with a total length of 2,44 m. Figure 2 shows the set-up of the Lateral Shuffle Test.

Figure 2- Lateral Shuffle Test set-up.

Then the test is recorded with the Xiaomi Pocophone F1 device. The test had a 10 second duration, measured with a stopwatch. The recording is analyzed, registering the score. This is obtained by adding every marker the participant crossed.

Procedures

F-V Profile

Approximately one week before the first data collection, each participant performed a familiarization session, experimenting the CMJ with different loads.

The warm-up phase consisted in 5 minutes on a stationary bicycle, in a moderate intensity. After, six jumps were made with three different loads (no external load, bar, bar + 10 kg), in a random order, with a 3-minute rest period after each jump.

After a 3-minute rest, the first jump is made with no external load. To simulate the bar, the participants had a simple plastic stick, to avoid, as much as possible, any biomechanical benefit. From a standing position, the participants start a downwards movement until they reach a squat position (around a 90º knee flexion), and then they jump as high as they can. After they rest 3 minutes, they repeat the same procedure one more time without additional load. Then, the participants performed two jumps with the bar (17,6 kg), with a 4-minute rest period between jumps, avoiding fatigue to affect the jumping ability. After, the same procedure is made with additional load on the bar. If the conditions for the jump were not met (failing a 90º knee flexion; not jumping vertically) the jump was repeated for that load. Two valid jumps were recorded for each load. To measure the jump height the MyJump2 app, was used. Balsalobre-Fernández et al., (2015), showed that “CMJ height can be easily, accurately and reliably evaluated” using this app. Therefore, using the measures mentioned before, we could study the F-V profiles of the table tennis players on the field.

COD

For the COD test, we used the Lateral Shuffle Test analyzed by McCormick (2014). With almost every COD test using straight running motions, the Edgreen side-step test is unique in analyzing lateral change of direction. This lateral shuffle is one of the main movement used by table tennis players while playing, with several quick changes of direction, making this test a close way to evaluate their movement performance. McCormick (data) concluded that the LST, with the 8 feet by 10 seconds variation, is a reliable and valid test to measure COD, and appropriate to be applied to sports with constant lateral movement and short time frame, as the table tennis.

After the participants usual warm-up, they performed 2-3 trials of the test to get familiarized. After 1-2 minutes rest, the LST test was performed, starting with the base position that they get used to play in, on the center line. On the researcher's verbal signal, the participants start the lateral shuffle to the left side. They change directions when the outside leg crossed the outside line. If the participant crossed their legs, the test was not valid. If these conditions were not met, the test was repeated. Two LST were recorded for every participant.

For both tests, the participants were informed about the procedures before, and were told to bring the equipment and shoes used to play. The best result between the two recorded, both in CMJ and LST were used for the statistical analyses.

Training Program Structure

Considering that the main goal of this study was to study the F-V profile of the participants, the training program aimed to improve vertical jump and reduce the F-V imbalance, and consequently improve the COD. Since the nine participants showed a force deficit, to reduce their imbalance the training program was designed focusing on strength, aiming to improve F0. This way we followed Jiménez-Reyes et al. (2017), with "two sessions per week, each separated by 48 h of recovery". The participants continued with their practices and competitions and refrained from additional lower body training outside our program. Six weeks was the time length stablished according to players competitions schedule and availability.

To warm-up, the participants performed 5 minutes on a stationary bicycle (moderate intensity), followed by 10 back squats with a 15 kg bar. Some players also felt the need to perform exercises of their usually warm-up routine. The training program consisted in two strength exercises (Back squat and deadlift) and one Strength-Power exercise (Loaded CMJ). For the strength exercises, the loads and the volume were suggested to be around 80% of one maximum repetition (%1RM). We followed a resistance training phasic progression (Suchomel et al., 2016). Going from a strength-endurance phase to a maximal strength phase, the participants would enhance their force production, as well as improve the technique and get more comfortable with the exercises. Lowering the volume and increasing the load closer to 1RM as a way to improving the participants force production capacity. In table 3 the strength exercises program is described.

For the strength-power exercise, the CMJ with additional loads was chosen. We established the load according to the participants bodyweight. Following the same logic, we planned a progressive volume and load for this exercise, as shown in table 4.

Back Squat + Deadlift		
Week	Volume (Sets x Reps)	Load (% RM)
1	3 x 8	60
2	3 x 6	65
3	3 x 5	70
4	4 x 4	75
5	4 x 4	75
6	3 x 3	80

Table 3 -Strength exercises volume and load

CM Jump		
Week	Volume (Sets x Reps)	Load (% BW)
1	3 x 8	20
2	3 x 6	25
3	3 x 5	30
4	4 x 5	35
5	4 x 4	40
6	3 x 4	40

Table 4 - Strength-power exercise volume and load

Statistical Procedures

For the statistical data treatment, we appeal to the IBM SPSS Statistics 27 software.

Descriptive statistics were calculated for all the variables, analyzing the mean, standard deviation, maximal and minimum values.

Firstly, through the Shapiro-Wilk test we examined the normality of the variables in this study.

Considering the low number of participants on this study (n=9), a non-parametric test (Wilcoxon Signed Ranks test), with a level of significance of $P \leq .05$, was used to investigate a possible significant change in the means, comparing the pre and post results of the F-V profile variables and the LST. This test compared the means of the variables before and after the training program. If there was a significant change between pre and post training values, we conclude that the training program affected the variable, in a positive or negative way, depending on if the means are higher or lower than the first collection.

The magnitudes of change were calculated with the effect size (ES), comparing the variables means, and understanding the impact of the changes on each value after the training program.

Results

The results of the non-parametric repeated measures test show a significant change for F0, V0, F/V_{IMB}, Hmax and COD mean values, with a significance value (p) lower than 0.05. Only the Pmax results did not demonstrate a significant change after the training program (p = 0515).

The F/V_{IMB} decreased significantly, from 43.44 % to 23.11%, indicating that the players reduced their force deficit. Regarding the CMJ height and the LST results, both showed an improvement from 0.32 m to 0.34 m and 36.89 to 38.78 respectively.

While the F0 increased from 32.12 to 36.99, the V0 values decreased from 3.53 to 3.08. The Pmax values did not present a significant change, with a difference of only 0.53 W/Kg between pre and post training program means.

The effect size standard change, presenting the magnitude of the mean changes, followed the scale 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). The qualitative probabilities are defined by the following scale: <0.5%, almost certainly not; <5%, very unlikely; <25%, unlikely; 25-75%, possibly, possibly not; >75%, likely; >95%, very likely; >99.5%, almost certainly. The decrease on the F/V_{IMB} was extremely large. A moderate change in the means was noted on the CMJ height, F0, V0 and LST results. The Pmax results, even though they did not significantly change, show a small standard change (0.25). The small change on Pmax is very unlikely to be negative.

The V0 and the F/V_{IMB} are very likely and almost certainly affected negatively, respectively. Nevertheless, this is a positive result, since the purpose of the training plan was to decrease the imbalance. This is corroborated by the significant decrease on both means. The LST and the F0 means show likely positive change, and the CMJ height shows a very likely probability of being positively affected after the training program.

Table 5 shows the results obtained after the Wilcoxon repeated measures test, and the effect size standard change calculation.

	Mean (S.D.)		Rep. Measures Test		Qualitative Probabilities (%)
Variables	Pre	Post	(p)	ES Std Change Mean (S.D.)	Positive/Trivial/Negative
CMJ Height (m)	0.32 (0.03)	0.34(0.02)	0.038	0.74(0.47)	98/3/0
F0 (N/Kg)	32.12(3.66)	36.99(4.80)	0.008	0.83(0.68)	94/5/1
V0 (m/s)	3.52(0.39)	3.08(0.48)	0.028	-1.03(0.66)	0/2/98
Pmax (W/Kg)	27.50(1.91)	28.03(1.98)	0.515	0.25(0.85)	54/28/17
F/V_{IMB} (%)	43.44(8.53)	23.11(18.01)	0.011	-2.15(0.94)	0/0/100
LST (score)	36.89(2.67)	38.78(3.77)	0.049	0.64(0.49)	93/6/1

Abbreviations: CMJ Height – Countermovement jump height; ES Std change – Effect Size standard change; F0 – Theoretical maximal force value; F/V_{IMB} – Force-Velocity Imbalance; LST – Lateral Shuffle Test; Pmax – Theoretical maximal power value; V0 – Theoretical maximal velocity value.

Table 5 - Repeated measures test ($p \leq 0.05$) and Effect size change

Discussion

Concerning the characteristics of the table tennis competition, explosive lower limb manifestation is an important factor on performance (Le Mansec et al. 2017, 2018). When analyzing the footwork used by players, results show high GRF, in different magnitudes across vertical, lateral and anterior-posterior plans, depending on the movement being executed (Lam et al. 2019; Zhang et al. 2013). These footwork movements are performed at a high-speed, trying to reach the better position possible to stroke the ball. Regarding the explosive strength required when playing table tennis, previous studies assessed the jump capacity as a good method to analyze the lower limb's strength and power expressions (Samozino et al. 2008, Jiménez-Reyes et al. 2014). On this study, we used the method developed by Samozino et al., in 2008 (Samozino et al., 2008), tracing the players F-V profiles. Considering the results of training programs focused on improving the F-V profiles, by reducing the F/V_{IMB} (Morin & Samozino, 2016; Jiménez-Reyes et al., 2017), we followed the same strategy, designing a training program focused on the deficit of the participant (force or velocity), aiming to improve jumping performance.

F-V Profiles

All the players in this study presented a force deficit, which may be explained by an influence of their training background, following the conclusions by Giroux et al. (2016). Even though this sample does not represent every table tennis player, the implications of years of table tennis practice may develop chronic adaptations, resulting in a more specific??? better??? velocity-based profile. This corroborates the findings of Pradas et al. (2011), that explain the necessity of explosive strength to perform high-speed movements, to reach an ideal position. As mentioned by Giroux et al. (2016), the background training, specific of the sport in question, may influence the F-V profiles of the athletes, which can also be used to detect promising young athletes. It may be of interest to investigate F-V profiles among a bigger sample in table tennis, trying to find a relation between high velocity values, and table tennis performance.

Figure 3 shows a comparison of the pre and post mean values for the F0, V0, F/V_{IMB} and Pmax. The F/V_{IMB} shows a clear decrease on the post training program values, while F0 shows an increase. The Pmax values remain similar. The V0 values show a slight decrease. This balance between F0 improvement and V0 decrease may explain the Pmax not improving. Since Pmax is dependent on the relation between F0 and V0, it is expected that when one increases and the other decreases, the Pmax stays without significant changes. This V0 decrease may be explained by the muscle adaptations the training program had on the lower limbs, since it was focused on improving the F0, aiming to get the F-V profile closer to the optimal. As hypothesized, the F/V_{IMB} decreased significantly, after the application of the training program. The CMJ height improved, and following the conclusions of Samozino et al. (2012), later endorsed by other studies (Samozino et al., 2013,2016; Jiménez-Reyes et al., 2014; Morin & Samozino, 2016), the decrease in the F/V_{IMB} resulted in a better jump height. The jump height improvement, without changes on the Pmax, supports the previous findings that the F-V Profiles also are an important parameter in vertical jump performance.

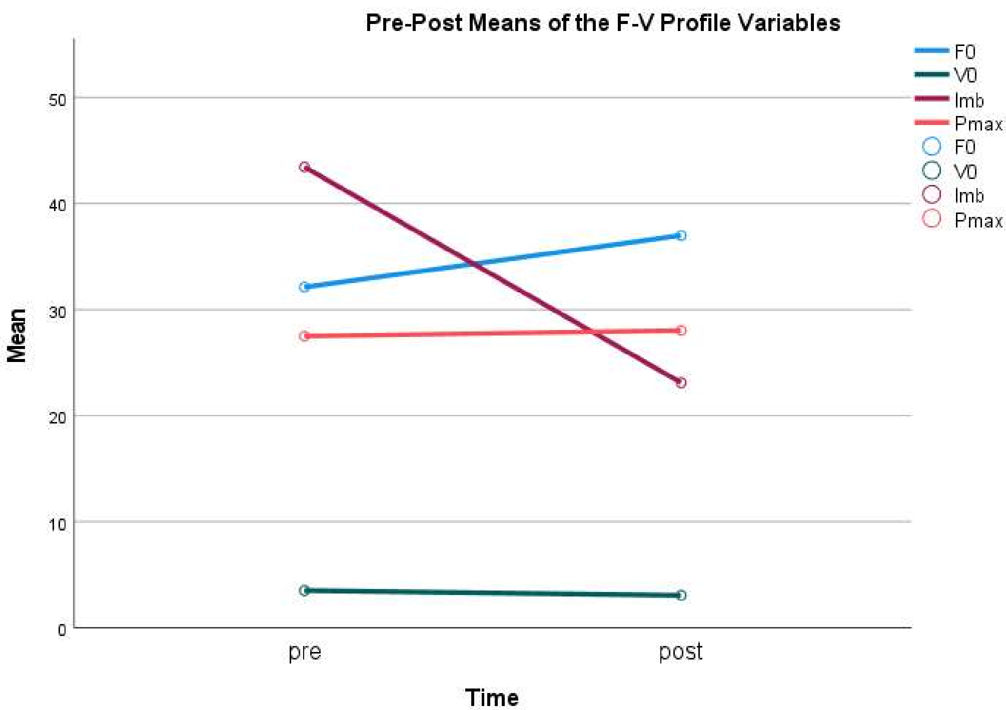

Figure 3 – Pre and Post training program mean values of the F-V Profile variables

Training Program

The training program applied consisted of two strength exercises (Back squat and deadlift), and a strength power exercise (loaded CMJ). These exercises were chosen since (i) they are commonly used to improve the lower limb strength and (ii) Jiménez-Reyes et al. (2017), used them in their training programs resulting in a reduction in the F/V_{IMB} . The results showed a significant decrease on the F/V_{IMB}, and an increase on CMJ height. Like previous studies indicate, weightlifting and plyometric exercises produce neuromuscular adaptations that result on better force production and jump performance (Suchomel et al. 2017; Kaabi et al. 2021). Considering that the back squat and deadlift are weightlifting progressions, while the loaded CMJ is a plyometric exercise, this combination may produce muscular adaptations on the lower limbs that explain the improvement of the jump performance.

Change of Direction

To improve change of direction, Miller et al. (2006) used a plyometric training plan, showing positive results on the T-Test. The eccentric-concentric actions, characteristic of the plyometric exercises, may result in neuromuscular adaptations, that improve the change of direction. These findings, corroborated by Dos'Santos et al. (2017,2018), suggest plyometric training improves COD, due to the eccentric-concentric actions and the rapid application of force, mentioned to be important factors in COD movements. The lower limb strength and rate of force development developed by plyometric exercises, complementing COD technique training, may be a good approach to improve this skill. Nevertheless, when Kaabi et al. (2021) compared the results of plyometric training and weightlifting exercises, both presented improvements. The weightlifting exercises result in power, speed, and strength improvements, characteristics known to be important in COD. This study also hypothesizes that the increase of eccentric strength of the lower limbs, caused by the weightlifting exercises, may improve the COD, influencing the deceleration and acceleration movements.

This study shows an improvement on COD, with a significant increase on the LST scores. Even though this COD test presents different characteristics when compared to the T-Test, the improvements may be related to the combination of strength and plyometric exercises, as suggested on previous studies (Miller et al., 2006; Dos'Santoes et al., 2017, 2018; Kaabi et al., 2021). The improvements on the LST results may be of interest to coaches, considering its similarity to the footwork used while playing table tennis.

The results show that the relation between the F-V profile and COD is important. The similar characteristics of the COD and the vertical jumps, such as stretch-shortening cycle and explosive strength, may explain why the COD improved in this sample. The training program used in this study, with weightlifting progressions (back squat and deadlift) and plyometric exercises (loaded CMJ), may cause neuromuscular adaptations that allow to perform better COD movements. These adaptations translate to a better force production and improved eccentric and concentric actions, both important in COD performance. We believe that the improvement of the F-V profiles can positively impact COD. This is new information that needs to be investigated, to expand the knowledge on the relation of COD and the vertical F-V profiles.

Limitations

This study presented some limitations, being the most relevant the sample size and the world pandemic situation.

First, to select the elite athletes to participate in this study, the sample was reduced to only nine players. All the participants in our study presented a force deficit, which reduced significant variables to be explored, like a velocity focused training program. We propose more investigation on this area, with bigger samples to better represent players' physical characteristics.

The constant training and competitions also presented some difficulties, considering that a longer training program, with more evaluation moments would be interesting to understand the adaptations that were occurring on the F-V profiles of the players, and possibly adapting the training program.

Due to the restrictions applied, concerning the Sars-CoV-2 pandemic, we had to articulate different ways to overcome some obstacles. The training hall, with a capacity of around 20 tables, was reduced to 8, creating a wider schedule, with multiple training sessions in the morning and afternoon. The gym, with a capacity of around 10 people was also reduce to 5 people. This way, according to the schedule of the players, we had to articulate different training session times, with no more than 3 players working simultaneously at the gym, also considering the competitions they had, and rest between sessions. Nevertheless, we organized this study so that every participant performed 2 training sessions a week, for 6 weeks, plus the evaluation moments, a familiarization session, and the session to evaluate the RM.

Considering the lack of information on strength and conditioning on table tennis, we explored a new approach to this area. Believing that we provided new information to coaches to complement their training programs, we propose more studies in this area, with larger samples and more evaluation moments, increasing the information and knowledge available.

Conclusions

In this study we investigated the effect of a six week-long training program, on the Force-Velocity profile and the Countermovement jump height, in a sample composed of elite table tennis players. As a second goal, we studied the change of direction. With the application of the Lateral Shuffle test, we investigated if a training program focused on improving jump height affected the change of direction.

As hypothesized, after the training program application, the imbalance between the players actual and optimal F-V profiles decreased significantly. The results show that the training program increased the F0 values, which balanced their profiles more towards the optimal. The V0 values decreased, which may explain the Pmax staying the same, since it depends on the relation between the F0 and V0.

The CMJ height also increased significantly after the six weeks. The training program appears to have had a positive effect on the lower limbs' explosive performance, considering the improvement on this explosive strength test.

This study also corroborates previous findings, supporting that the F-V profiles of the athletes are an important factor of jump height performance. This is explained by the improvements on CMJ height, even though the Pmax values do not increase.

Regarding the COD performance, the results show a significant increase in the LST results. The improvement of force values and jump height affected the ability to perform the COD in this sample, even though the training program did not incorporate any COD movements. We conclude that the improvement of force production and jump height has a positive impact on COD.

Considering the similarity between the LST and the table tennis footwork, we believe that improving this COD variant may have positive effects on table tennis performance. Nevertheless, more investigation on this area is necessary to better understand these possible relations.

This study used a recent method developed on strength and conditioning, applying it on table tennis athletes. Since there is not a lot of investigation on this subject, we believe to have contributed to the knowledge on strength and conditioning on table tennis.

We suggest more investigation on this area, seeking a better understanding of the physical necessities of this sport, making available more information for coaches to better compliment their training programs.

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Attachment A: Declaration of Consent

Declaration of Consent

Introduction: This is a study is a Dissertation with the view to obtain the 2nd cycle in Sports Training, specialization in High Performance Training, from the Faculty of Sports of the University of Porto.

Advisor: Filipe Almeida Vieira da Conceição
Procedures: Firstly, a familiarization session with the equipment and procedures is held. The study consists on an evaluation moment, the application of a training program during 6 weeks, and a final evaluation moment. The evaluation consists of a Countermovement jump test, with a battery of jumps with different loads, and a Change of Direction test. With the results of the Countermovement jumps, the Force-Velocity profiles will be traced. Then, considering your personal Force-Velocity imbalance, a training program will be designed, aiming to improve your vertical jump and decrease your imbalance. After the 6 weeks, another evaluation is held. Then, the results will be examined statistically, looking for any significant changes.

Goals: The goals of this study are: (i) to investigate the effects of a 6 week training program on the Force-Velocity profiles and Countermovement jump height; (ii) to investigate if the training program focused on vertical jump and Force Velocity Imbalance alters the Change of Direction performance.
Confidentiality: This study is anonymous, and the results are for academic purposes only.
Voluntary Participation: The participation on this study is voluntary. You can refuse to participate at any moment.

I declare to have read and understand this document and the instructions given. This way I agree to participate in this study, trusting the confidentiality and that the results will be used for academic purposes only.

Name:

____

Signature:

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Researcher's signature:

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Data: _____ /_____ /_____