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Training program application and its effects on Force-Velocity profile and interference on front tuck execution in elite Acrobatic gymnasts

During a special transition period followed by a specific preparation and a pre-competitive period

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Dissertation presented with the purpose to obtain the 2nd cycle in Sports Training, specialization in High Performance Training, from the Faculty of Sports of the University of Porto, under the Executive-Order No. 74/2006, of March 24, in the wording given by Executive-Order nº 65/2018 of August 16.

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General Index

Figure index

Table index

Attachment index

Resumo

O objetivo deste estudo foi investigar o comportamento do perfil Força-Velocidade (F-V) vertical durante o *Counter Movement Jump* de atletas de 1ª divisão e elite de Ginástica Acrobática antes e após a aplicação de um programa de treino durante um período transitório especial e a sua interferência na execução do mortal à frente. 28 ginastas de 1ª divisão e elite com idades compreendidas entre 11 e 25 anos foram divididos aleatoriamente em grupo controlo (GC) de ginastas volantes (n=4), grupo intervenção (GI) de ginastas volantes (n=7), GC de ginastas bases (n=9) e GI de ginastas bases (n=8). *MyJump2* foi o instrumento utilizado para avaliar o desequilíbrio entre F-V (F-V Imb). Foi utilizada a Anova Mista para 2 momentos de avaliação para todas as variáveis do perfil F-V ($P \leq 0.05$) e foi calculado o *Effect size* (ES) de Hopkins (2004). Por fim, realizaram-se gravações do mortal à frente e um questionário para compreender a influência da altura de salto na perceção de execução do elemento após o programa (análise através de um teste T de medidas repetidas). Não houve diferenças significativas entre os grupos ao longo do tempo. Contudo, algumas das variáveis intra grupo melhoraram de forma relevante. Os ginastas bases do GI melhoraram 1.06 (1.56) cm na altura de salto e 23.75 (4.16) % no F-VImb com ES de -1.19 e 100% de probabilidade de o programa ter tido um efeito negativo já que o objetivo era diminuir este valor. O F-VImb dos ginastas volantes do GI não melhorou, contudo, a altura de salto aumentou 0.86 (0.05) cm e os valores de força melhoraram 5.59 (5.47) N/kg com ES de 1.29 e 90% de probabilidade de o programa ter tido um efeito positivo nesta variável. Por fim, houve diferenças significativas no GI ($P=0.013$) na análise da perceção da execução do mortal à frente. Concluímos que o programa de treino de 9 semanas foi eficaz, já que, apesar dos pesos dos ginastas dos GI apresentarem diferenças significativas durante o período transitório especial no qual se encontravam, o programa de treino conseguiu mitigar os efeitos negativos desse aumento de peso através da melhoria das variáveis mecânicas do perfil F-V, da altura de salto e da capacidade específica de salto associada a esta disciplina gímnica.

Palavras-chave: PERFIL FORÇA-VELOCIDADE; GINÁSTICA ACROBÁTICA; IMPULSÃO VERTICAL; MORTAL À FRENTE; TRANSFERE ESPECÍFICO

Abstract

The purpose of this study was to investigate the vertical Force-Velocity (F-V) profile behavior during the Counter Movement Jump of 1st division and elite Acrobatic gymnasts before and after the application of a training program during a special transition period and its interference in front tuck execution. 28 acrobatic gymnasts from 1st division and elite groups with ages between 11 and 25 years old were randomly divided in top gymnasts control group (CG) (n=4), top gymnasts intervention group (IG) (n=7), base gymnasts CG (n=9) and base gymnasts IG (n=8). MyJump2 was the instrument used to evaluate the F-V Imbalance (F-V Imb). A Mixed Anova for 2 evaluation moments was used for all F-V profile mechanical variables ($P \leq 0.05$). Hopkins (2004) effect size (ES) was used to calculate the magnitudes of change. Lastly, front tuck documentation and a survey were used to evaluate the influence of jump height on the front tuck execution perception after the training program (data analyzed through a repeated measures T test). There were no significant differences between all groups over time. However, some of the intra-group variables improved considerably. Base gymnasts IG improved their jump height in 1.06 (1.56) cm and their F-VImb in 23.75 (4.16) % with a ES of -1.19, indicating a 100% probability of a negative effect from the program since our goal was to decrease this value. Although top gymnasts IG F-VImb did not improved, they improved force values in 5.59 (5.47) N/kg with a ES of 1.29 and 90% chances of a positive effect from the program and their jump height in 0.86 (0.05) cm. Lastly, there were significant differences in the IG ($P=0.013$) in the front tuck execution perception analysis. We concluded that the 9-week training program was effective since even though there were significant differences in intervention groups weights and gymnasts were in a special transition period, the program managed to mitigate these negative effects by improving F-V profile mechanical variables, jump height and gymnasts specific jumping ability associated with this gymnastics discipline.

Keywords: FORCE-VELOCITY PROFILE; ACROBATIC GYMNASTICS; VERTICAL JUMP; FRONT TUCK; SPECIFIC TRANSFER

List of abbreviations

BMI – Body mass index

BW – Body weight

CMJ – Counter Movement Jump

ES – Effect size

FIG - Fédération Internationale de Gymnastique

F-V profile - Force-Velocity Profile

F-VImb - Difference between the current and the optimal profile for each athlete

F0 - Theoretical maximal force

HPO - Height of Push Off

RFD - Rate of Force Development

NSCA – National Strength and Conditioning Association

Pmax - Maximal power output developed by the lower limbs

ROM – Range of motion

SJ – Squat jump

SSC – Stretch Shortening Cycle

V0 - Theoretical maximal velocity

Introduction

According to Acrobatic Gymnastics code of points “(…) Each exercise is evaluated for its nearness to criteria for perfection of performance (…) Consideration is given by the Execution Judges to the amplitude and technical correctness of each element performed. This concerns the amount of stretch, body tightness and fullness of movement i.e. how much of the maximum amount of space possible for the element being performed is used. Pair, group and individual elements are each given attention” (Fédération Internationale de Gymnastique, 2017, p. 33).

Fédération Internationale de Gymnastique (2017) points the following evaluation criteria: efficiency in technical execution, correctness of line and shape, amplitude in the execution of pair/group and individual elements: full stretch in balance elements and maximum flight phase in dynamic elements, stability of balance elements, effective catches, pitches and throws and landing control.

Execution faults are penalized by deductions from the maximum score of 10.00 each time they occur, using the following penalty scale: small faults (0.1), significant faults (0.2 - 0.3), serious faults (0.5) and fall (1.0) (Fédération Internationale de Gymnastique, 2017).

According to Montalvo & Dorgo (2019), an increased jumping performance can be critical for competition purposes in gymnastics since this sport requires rapid expression of explosive strength which is expressed through vertical jump. In this sense, a problem aroused “What would be the behavior of the Force-Velocity profile during vertical jump before and after the application of a training program specifically designed to improve jumping performance?”. Through this work, we will try to answer this problem and, consequently, help to enhance acrobatic gymnastics coaches’ practices in the daily training context.

Although the F-V profile is documented in the literature, where is possible to highlight primarily the authors Samozino et al. (2008) and, later, Jimenez-Reyes et al. (2016), it was not possible to find studies within this matter in Acrobatic Gymnastics. There are some limitations, namely difficulties in finding scientifically grounded guidelines and, due to the reduced number of 1st division and elite athletes, the sample does not present the desired number of gymnasts. However, it is required to invest in this area so that scientifically based knowledge can evolve and help coaches in the context of training to improve their practices. In this sense, the present investigation aims to develop a new subject in this gymnastics discipline, providing new information to the literature.

This work is aimed, firstly, to investigate the vertical Force-Velocity profile behavior during the Counter Movement Jump of 1st division and elite gymnasts before and after the application of a training program specifically designed to improve jumping performance during a special transition period. After applying the training program, the transfer to Acrobatic Gymnastics specificity is assessed through the evaluation of a gymnastics element. Front tuck documentation (before and after the application of the training program) is evaluated by qualified judges and coaches to analyze the influence of jump height in the front tuck execution perception.

Initially, this work intends to define the current state of knowledge in the subject in which the project is developed through the literature review. In this stage, studies carried out with adults and studies regarding young athletes will be presented considering the diversity of our sample. Thus, it will be possible to understand what the literature already knows about the topic and what can be done to improve the existence knowledge.

Afterwards, main and specific objectives and hypothesis are presented to describe objectively what is intended to be investigated.

The next stage corresponds to the material and methods description including study variables, the transfer to the gymnastics discipline and the statistical procedures. At this stage, sample characterization is relevant considering that conducting research in the context of high-performance training is a complex process.

After that, we present the results and the discussion aiming to stablish a confrontation between the present investigation and the information provided by the literature.

Finally, it remains to present the investigation main conclusions where the hypotheses verification and the answer to the problem are the most important aspects since it allows to understand if the work was capable of answering these hypotheses and the problem formulated.

Literature review

Training prescription and periodization

Training prescription consists in a process, which begins with individual needs and training goals determination (Kraemer & Ratamess, 2004). Training must be designed considering "(…) choice of exercises, order of exercises, amount of rest used between sets and exercises, number of repetitions and sets used for each exercise, and the intensity" (Kraemer & Ratamess, 2004, p. 1).

The same authors refer multiple ways to progress overtime to promote muscular fibers maximal recruitment and, consequently, to increased hypertrophy and muscular fibers strength, such as increased load, increased repetitions with the current load, variations on the repetition speed, shorter rest periods to improve local muscular endurance or longer periods for strength and power training, increased volume or a combination of the items above (Kraemer & Ratamess, 2004).

In addition, to emphasize the importance of specificity, these authors present the example of a training plan aiming to improve jump height. In this case, the training program would include "(…) specific exercises (for example, squat, jump squat, power clean) that mimic vertical jumping, and these exercises would be performed at high speed to maximize power output" (Kraemer & Ratamess, 2004, p. 10). This example indicates that all adaptations to training are specific to the stimulus applied (Kraemer & Ratamess, 2004).

Another fundamental aspect linked to sports training is its periodization. This concept refers to the general and detailed planning of the available time for training that should always comply with the principles of sports training and contemplate the goals established (Dantas, 2003).

Is it possible to highlight some of the most well-known authors in this subject, such as Weineck (1989), Verkhoshansky (1995), Matveev (1997), Platonov (2001), Bompa (2002) and Dantas (2003).

Although these authors established distinct theories, they all provided their contribute to the development of this subject. The next goal of this review is to highlight the fundamental aspects related to a sports season periodization since this subject is linked to the intention of the thesis.

Primarily, there are three main structures important to mention. The macrocycle structured in annual periods and divided in mesocycles, in which each physical quality is developed in periods of four to six weeks, subsequently divided in microcycles, referring to one week periods where training loads are determined according to the week goals (Bompa, 2002).

The same author refers that the macrocycle is a previously designed training plan which includes training, competition and recovery periods carried out over a season, aiming to lead the athlete/team to a level of conditioning that enables them to perform under the required conditions. According to Dantas (2003), the traditional macrocycle prioritizes one competition, which is a strategy used by coaches in Olympic games seasons and other major competitions (world championships and record attempts).

On the other hand, the mesocycle can be defined as the periodization structural element referring to periods ranging from 21 to 35 days since this is the minimum time required for the adaptations in the intended physical qualities to happen, according to the knowledge of general adaptation (Matveev, 1997) .

Finally, to create optimal conditions for overcompensation phenonium to occur, the microcycle combines phases of stimulation and recovery to improve athletes level of conditioning (Matveev, 1997).

Bompa (2002) divides the sport season in three periods: preparatory period, subdivided into general and specific phase, competitive period, subdivided into pre-competitive and competitive phase and transition period (Figure I).

Annual plan					
Training periods	Preparatory		Competitive		Transition
Subphases	General	Specific	Pre-competitive	Competitive	Transition
Macrocycles					
Microcycles					

Figure I - Annual training plan. Adapted from Bompa, 2002

According to Matveev (1997), the preparation period involves two phases: the general phase, which emphasizes physical preparation, training general component and volume over intensity since the main goal is to achieve the previously established competitive level and the specific phase, characterized by technical-tactical training and predominance of intensity over volume.

Matveev (1997) refer that athletes reach their maximum performance levels during competition period. Before the main competitions, Bompa (2002) recommends a recovery period, referred as polishing macrocycle to remove fatigue and to facilitate the occurrence of overcompensation, through decreased training loads during a maximum of two weeks.

Finally, the transition period which is characterized by very low intensity levels to provide physical and psychological recovery after competitions (during approximately one month) (Matveev, 1997). In addition, loads are repressed and recovery microcycles with progressive loads are often used to prepare for the next macrocycle (Bompa, 2002).

It remains to be noted that over the years and a repetitive accumulation of these type of loads, the subsequent preparatory periods are further shortened, with a higher specificity of training (Bompa, 2002).

Force-Velocity profile: adults training

Currently, it is known that ballistic performances are a key factor in numerous sport activities and can be defined as the ability to accelerate a mass as much as possible promptly referring to one's own body mass (e. g. sprints or jumps) or an external mass (e. g. throws) (Samozino et al., 2014).

Therefore, force and velocity are considered fundamental features of mechanical power output in sport movements, which depends on the ability of athlete's neuromuscular and osteoarticular systems to generate high levels of force and apply it effectively onto the environment (Cormie et al., 2011a, 2011b).

In order to develop jump ability, Samozino et al. (2012) highlight that high ballistic performances are determined both by maximizing maximum power capacities and by optimizing the mechanical force-velocity profile (F-V) of the lower limb neuromuscular system. It is important to note that there is, for each individual, an optimal F-V profile that maximizes ballistic performance and represents the optimal balance between strength and speed qualities for these movements (Samozino et al., 2014; Samozino et al., 2012).

Studies carried out with adult athletes concerning the F-V profile suggest that a force deficit-oriented training program should focus on increasing the maximal power output of the lower limbs (Pmax) and decreasing the difference between the athletes current and optimal profile – Force Velocity Imbalance (FVimb) through increasing strength as a priority (Samozino et al., 2012). For this purpose, Jimenez-Reyes et al. (2016, p. 2) suggest "(…) trainings involving the use of high loads (>70% RM), in order to achieve the maximal neuromuscular adaptations, in periods ranging from 6 to 12 weeks". The possible explanatory mechanisms for changes in maximum strength may be associated with increased neural conduction and improved intermuscular coordination (Cormie et al., 2010) and rate of recruitment of motor units and the activation of type II muscle fibers (Cormie et al., 2011a).

On the other hand, in the case of a velocity deficit, "(…) training should aim to increase Pmax by improving maximal velocity capabilities (i.e., capacity to produce force at very high contraction velocities)" (Jimenez-Reyes et al., 2016, pp. 2-3). The effects of this type of training, often referred to as ballistic, can be seen in studies where protocols with a removed deceleration phase have been more effective (Newton et al., 1996; Cormie et al., 2010 cit. por Jimenez-Reyes et al., 2016). Changes induced by velocity training may include "(…) changes in neural activation patterns (i.e., lowered motor unit recruitment thresholds, improved motor unit firing frequency, and possibly synchronization, greater and/or more effective recruitment of fast-twitch muscle fibers) and enhanced intra- and intermuscular coordination" (Sale, 1988; Behm and Sale, 1993; VanCutsem et al., 1998; de Ruiter et al., 2004, 2006 cit. by Jimenez-Reyes et al., 2016, p. 9).

Lastly, in the case of a low deficit, referring to individuals who have a current F-V profile close to the optimal profile, "(…) the training program should target a balanced combination of force, velocity, and power in order to shift the entire F-V relationship to the right, and so to increase Pmax as a priority" (Wilson et al., 1993; Harris et al., 2000; McBride et al., 2002; Kotzamanidis et al., 2005; e.g., Cormie et al., 2007; de Villarreal et al., 2011 cit. by Jimenez-Reyes et al., 2016, p. 3) while maintaining the F-V profile close to the optimal value (and thus FVimb close to 0%) (Jimenez-Reyes et al., 2016, p. 3).

In this matter, it has been shown that a training program based on the imbalance of the individual F-V profile is more effective in improving jumping performance than a traditional resistance training developed without considering individual differences in the initial F-V profiles in adults (Jimenez-Reyes et al., 2016). According to the same authors, there were improvements in jumping height in all subjects with strength or velocity deficits associated with "(…) a markedly reduced FVimb for both force-deficit (57.9 ± 34.7% decrease in FVimb) and velocity-deficit (20.1 ± 4.3%) subjects, and unclear or small changes in Pmax (−0.40 ± 8.4% and +10.5 ± 5.2%, respectively)" (Jimenez-Reyes et al., 2016, p. 1). Through these results, it appears that imbalances in the F-V profile can be considered potentially useful variables to prescribe optimal training to improve ballistic performance (Jimenez-Reyes et al., 2016).

These authors also reported that this higher jumping performance is associated with the sensitivity of the F-V profile to the specific training program adapted to the individual athlete's needs, which led to a smaller F-V imbalance without changes in Pmax (Jimenez-Reyes et al., 2016). Since ballistic performances are determined by Pmax and by the individual F-V profile, an optimal training program should aim at increasing Pmax and/or reducing F-VImb and should be adapted to the individual F-V profile to increase its efficiency (Jimenez-Reyes et al., 2016).

However, all of this factors must be considered recognizing that as the athlete's level and depth of training background increases, the difficulty to produce training adaptations in maximal power activities such as vertical jump also increases (Kraemer & Newton, 2000). These authors highlight the athlete status regarding muscular strength in fast and slow muscle actions, rate of force development capability, stretch shorten cycle ability, intermuscular coordination and skill. The greatest improvement in maximal power production are related to a range of training methodologies that address each of these components (Kraemer & Newton, 2000).

Acrobatic Gymnastics

Since Acrobatic Gymnastics does not have a vast development around scientific research, it was not possible to find studies regarding the application of the F-V profile in this discipline. For this reason, our study is highly relevant.

Initially, it consists of a relatively modern gymnastics discipline, with four decades of history and it was the last gymnastics discipline to belong to the International Gymnastics Federation (FIG) in 1999 (Vernetta et al., 2019).

The International Federation of Sports Acrobatics was dissolved in 1998 and the discipline was adopted by the International Gymnastics Federation, aiming to unite all the Gymnastics disciplines and to make Acrobatic gymnastics an Olympic sport. The 16th World Championships and the first FIG world championships took place in Ghent, Belgium in 1999. Since 2007, the discipline has been known as Acrobatic Gymnastics and China and Russia teams dominate in international competition, while nations like Great Britain and Belgium have dramatically improved (Fédération Internationale de Gymnastique, 2020a).

According to Fédération Internationale de Gymnastique (2020b), competitive Acrobatic Gymnastics consists of five group formations: Women's Pair, Men's Pair, Mixed Pair, Women's Group and Men's Group. Each pair or group performs three routines - balance, dynamic and combined where gymnasts perform static elements such balances and holds and dynamic elements such as lifts, throws with complex somersaults and twists and tumbling skills (Fédération Internationale de Gymnastique, 2020b).

Regarding the age groups, according to Federação de Ginástica de Portugal (2017), 1st division and / or elite age groups are divided as follows: Age Group 1 (11-16 years old), Age group 2 (12-18 years old), Junior Elite (13-19 years old), Senior (from 12 years old) and Senior Elite (from 14 years old). However, to belong to the Junior Elite and Senior Elite age groups, it is necessary to reach a minimum final access score of 51,000 points beyond age, while to belong to the Youth, Junior and Senior age groups gymnasts must reach the required ages, in addition to meeting the technical requirements that the execution requires (Federação de Ginástica de Portugal, 2017).

It is also important to highlight that “(…) pairs or groups who have competed in World Championships, World Cup, World Games or as Seniors in Continental Championships may not compete in the Age Group Competitions. Individuals who have competed as Seniors, but who are in newly formed age group pairs or groups are eligible (…) A gymnast may only participate in one Age Group and unit (pair/group) during same competition (WAGC). A Pair/Group can only move up in age groups, i.e. from 11-16 to 12-18 or from 12-18 to 13-19. A gymnast can move down in age groups, i.e from 13-19 to 12-18 only if he/she belongs to a different unit” (Fédération Internationale de Gymnastique, 2017-2020, p. 5). These criteria can help to understand how the levels progression is structured in Acrobatic Gymnastics.

Youth training

Although it was not possible to find studies regarding the application of the F-V profile in youth, since this gymnastics discipline age groups’ incorporate young and adults gymnasts, it is necessary to include some considerations concerning youth training in this review.

The National Association of Strength and Conditioning (NSCA) argues that an idealized and supervised training program can have several advantages for youth, namely improving (i) muscle strength and power, (ii) cardiovascular risk profile, (iii) motor skills performance, (iv) resistance to sports-related injuries, (v) psychosocial well-being and, finally, (vi) promotion and development of exercise habits during childhood and adolescence (Faigenbaum et al., 2009).

The same authors also mention that, although there are still some concerns regarding the safety or effectiveness of youth training, scientific evidence clearly demonstrates the health and performance benefits for these age groups. As long as the training follows the appropriate guidelines and has qualified supervision, it is essential that professionals recognize its benefits for young people health, namely with regard to bone health, body composition and reduction of sports injuries (Faigenbaum et al., 2009).

The same authors emphasize as future research goals the understanding of the mechanisms responsible for the health benefits of youth training and the establishment of a combination of variables that can optimize long-term training adaptations and adherence to exercise with children and youth (Faigenbaum et al., 2009).

With regard to prescriptions, NSCA recommends "(…) heavy resistance multi-joint exercises should not fall below six to eight repetitions for adolescents; plyometric exercises should not exceed six to eight repetitions and that the focus should be on fewer quality repetitions" (Dowse et al., 2017, p. 13). Indeed, Potteiger et al. (1999) suggest that the information from their research supports the use of plyometric training to improve jump height and lower limb power production. However, according to Behm et al. (2017) meta-analysis, strength training must be performed prior to power training to develop strength levels suitable for the demands of power exercises.

Up to now, there is sufficient evidence to conclude that resistance-training interventions can improve muscular power in adolescent athletes (Harries et al., 2012). A systematic review and meta-analysis conducted by these authors revealed a positive effect for resistance training programs on vertical jump performance in adolescent athletes (mean difference 3.08 [95% CI 1.65, 4.51], $Z = 4.23$ [$P < 0.0001$]).

Training considerations for young gymnasts

When applying the previous contents to gymnastics, Dotan et al. (2013) refer some important aspects to consider when prescribing training with young gymnasts. First, it has been demonstrated that the maximum voluntary activation of motor units is lower in children than in adults (Grosset et al. 2008; O'Brien et al. 2010; Paasuke et al. 2000 cit. by Dotan et al., 2013) and that children have a deficit in the activation of type II fibers (Dotan et al., 2012), while in gymnasts there may be a greater activation of these fibers (Halin et al., 2002). As an example, “(…) enhanced elbow flexion (EF) performance of gymnasts is largely training-acquired, rather than an innate, preselection characteristic” (Dotan et al., 2013, p. 4). These factors may be associated with gymnastics training specificity, as it promotes explosive muscle contractions that can increase not only maximum strength, but also the rate of force development (Dotan et al., 2013). It is important that all coaches consider these aspects to provide a properly prescription.

Due to the reduced scientific research carried out in Acrobatic Gymnastics, there are few studies that address the subjects in question. It was possible to select only two studies in this sport referring to injury prevention. Vernetta et al. (2019) suggested the use of progressive loads as a crucial factor due to the weight that the bases support on the spine and they emphasize that the top gymnast performs movements that can generate contusions. For these reasons, training must be planned according to gymnasts’ age, always aiming to their well-being and health (Vernetta et al., 2019).

Aims and hypotheses

Main goal

To investigate the vertical Force-Velocity profile behavior during the Counter Movement Jump of 1st division and elite acrobatic gymnasts before and after the application of a training program during a special transition period and its interference in front tuck execution.

Specific goals

To evaluate the F-V profile and associated variables during *Counter Movement Jump* of 1st division and elite gymnasts before and after the application of a training program by specialty (base and top gymnasts).

To analyze jump height during Counter Movement Jump before and after the training program.

To analyze the influence of jump height in the front tuck execution perception before and after the training program.

Hypotheses

Hypothesis 1: The training program decreased the F-V imbalances from the top gymnasts' intervention group.

Hypothesis 2: The training program decreased the F-V imbalances from the base gymnasts' intervention groups.

Hypothesis 3: Intervention groups jump higher than the control groups after the training program.

Hypothesis 4: Jump height changed the front tuck execution perception of the intervention group.

Methods and procedures

Selection criteria and general characterization of the gymnasts from the training program sample

For this study, the selection criteria established consisted in acrobatic gymnasts from the 1st division and elite age groups with ages between 11 and 25 years old from the same club. To attend this criteria, twenty-eight Portuguese gymnasts from Age Group 1 (11-16 years old), Age Group 2 (12-18 years old), Elite Junior (13-19 years old) and Elite Senior (from 14 years old) were randomly divided by specialty in base gymnasts control group (n=9), base gymnasts intervention group (n=8), top gymnasts control group (n=4) and top gymnasts intervention group (n=7). In tables 1 and 2 are presented the anthropometric data and training characteristics of the gymnasts.

Table 1. Age group, level and gymnasts' parents sport experience (Mean (%))

Variables	Base gymnasts Control Group (n=9)	Base gymnasts Intervention Group (n=8)	Top gymnasts Control Group (n=4)	Top gymnasts Intervention Group (n=7)
Age groups	3 age group 1 (33.33%) 3 Junior (33.33%) 3 Senior (33.33%)	1 age group 1 (12.50%) 3 Junior (37.50%) 4 Senior (50%)	2 age group 1 (50%) 2 Junior (50%)	2 Junior (28.57%) 5 Senior (71.43%)
Level	6 1st division (66.67%) 3 1st division and elite (33.33%)	3 1st division (37.50%) 5 1st division and elite (62.50%)	3 1st division (33.33%) 1 1st division and elite (66.67%)	2 1st division (28.57%) 5 1st division and elite (71.43%)
Parents with sports experience	6 Yes (66.67%) 3 No (33.33%)	6 Yes (75%) 2 No (25%)	4 Yes (100%)	7 Yes (100%)

Table 2. Anthropometric data and training characteristics of the gymnasts (Mean (SD))

Variables	Base gymnasts Control Group (n=9)	Base gymnasts Intervention Group (n=8)	Top gymnasts Control Group (n=4)	Top gymnasts Intervention Group (n=7)
Age (years)	16.64 (2.33)	19.59 (3.22)	12.03 (1.38)	14.56 (2.08)
Weight (kg)	60.29 (8.63)	65.65 (12.55)	28.45 (4.64)	38.54 (6.32)
Height (cm)	167.44 (5.64)	167.88 (6.75)	136 (4.97)	151 (7.17)
BMI (kg/m²)	21.46 (2.62)	23.10 (2.58)	15.30 (1.37)	16.79 (1.21)
HPO (cm)	39 (6.06)	37.38 (4.66)	29.50 (3.42)	34.21 (4.04)
Years of practice (years)	7.67 (3.08)	9.13 (3.94)	5 (2.94)	8.29 (3.15)
Hours training/day (hours)	4.78 (0.44)	5 (0.00)	4.75 (0.50)	5 (0.00)
Trainings/week (number)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)
Hours training/week (hours)	28.67 (2.65)	30 (0.00)	28.50 (3)	30 (0.00)

As seen in table 1, each group was constituted by gymnasts from different age groups, varying between first division and elite level. Regarding years of practice (table 2), top gymnasts control group presented less years than the other groups (5 (2.94) years) since this is the youngest group (12.03 (1.38) years old). On the other hand, gymnasts from base control group, base intervention group and top intervention group presented 7.67 (3.08); 9.13 (3.94) and 8.29 (3.15) years of practice, respectively.

Other variables allow us to verify that the training volume is very similar for all gymnasts. Hours of training per day range from 5 (0.00) and 4.75 (0.50) hours, 6 training sessions per week and hours of training per week varying between 28.50 (3) and 30 (0.00) hours (table 2). Regarding parents' sport experience, it may be considered an indicator of family compromise.

It is important to mention that the training program was introduced after the European Championship, which consisted in the most important competition of the sports season. This suggests that in the beginning of the training program, gymnasts were in a post competitive period, in other words, in a special transition period (active recovery) where the volume and intensity of the habitual training decreased considerably for one month (November). Afterwards, the volume and intensity started increasing progressively over time, which corresponded to specific preparation period (December). Finally, in the end of the training program gymnasts were in a precompetitive period since in the last week they participated in a competition (last week of January). These factors will always be considered throughout this work.

Selection criteria and general characterization of the survey sample

In tables 3 and 4 is presented the survey responders' characterization.

Table 3. Survey responders' sex, nationality and formation characterization

Variables	N	Mean (%)
Sex	6	5 Female (83.33%) 1 Male (16.67%)
Country	6	Portugal (100%)
Sports formation	6	2 No (33.33%) 4 Yes (83.33%)
Coach degree	6	1 None (16.67%) 2 Level I (33.33%) 3 Level II (50%)
Judge course	6	2 Yes (33.33%)

Table 4. Survey responders' age and experience characterization

Variables	N	Mean (SD)
Age (years)	6	27.17 (4.67) years
Gymnast experience (years)	6	8.50 (5.28) years
Coaching experience (years)	6	6.80 (2.39) years
Judging experience (years)	6	2 (1.41) years

When constructing the survey, we attempted to follow Collins (2003) recommendations, namely that responders were able to understand the questions being asked, that questions were understood in the same way by all of them, and that they were willing and able to answer such questions. To ensure these aspects, national acrobatic gymnastics coaches and judges were selected. Four coaches and two acrobatic gymnastics judges with national category participated in the survey, five female and one male. The average age was 27.17 (4.67) years old (table 4). All the responders were former gymnasts. The coaches had an average experience of 6.80 (2.39) years and the judges 2 (1.41) years (table 4). Four of the responders were from Sports Universities and five had a coach degree (table 3).

Study variables

This study presents the following variables: weight, height, body mass index (BMI), gymnasts' practice level (first division and elite), their specialty (base or top) and their sports experience (including years of practice, hours of training per day, number of training sessions per week, number of training hours per week and parents' sports experience which may be an indicator of family compromise). In addition, there are other variables directly related to the F-V profile, namely the length of the right lower limb in the lying position (from the trochanter to the metatarsal in plantar flexion); the vertical distance between the ground and the great trochanter of the right lower limb at a 90° angle to the knee; the h_{PO} measure which refers to the difference between the two measures mentioned above and jump height; the imbalance between the F-V profile presented by the gymnast and his optimal F-V profile (F-V imbalance); maximum power developed by the lower limbs (Pmax) and also theoretical maximum force (F0) and theoretical maximum velocity (V0): “F-V curves were extrapolated to obtain F0 (then normalized to body mass) and V0, which respectively correspond to the intercepts of the F-V curve with the force and velocity axis” (Jimenez-Reyes et al., 2016, p. 3).

Anthropometric data

Prior to the anthropometric data collection, a specific training session of preparation to collect this data was held on October 5th, 2019. It is important to note that there were two moments of data collection (before and after the training program). The first data collection took place between November 4th and November 8th and the last collection from January 20th to January 24th in the club since the training program lasted 9 weeks.

To collect h_{PO} measure, a measuring tape and a goniometer were used. According to Gouveia et al. (2014) this instrument is highly reliable for measuring joint range of motion. Finally, the height and weight of the subjects were collected using a stadiometer and an electronic scale, respectively. To collect both measures, participants were barefoot and wore as little clothing as possible.

Procedures and instruments

After the warm-up period, a brief familiarization with the equipment and the CMJ movement was allowed.

Before each jump, participants were instructed to remain in a standing position with their hands on their hips for attempts without additional load and on the bar for attempts with external load. The position of the hands is maintained throughout the movement. From this position, participants performed a CMJ as described elsewhere (Jimenez-Reyes et al., 2014).

Each subject performed maximum countermovement jumps from 3 to 5 random loading conditions. Loads were applied progressively, and each load increment was around 5kg, depending on gymnasts' capacity. Studies carried out within the scope of the F-V profile recommend two attempts with a 2-minute interval (Samozino et al., 2014; Samozino et al., 2012). Samozino et al. (2014) suggest an interval of 4-5 minutes between attempts using additional load. To properly conclude the evaluation, participants must be able to jump between 15 and 18cm with the last load selected.

MyJump2 was the instrument used to measure jump height. It consists of a scientifically validated mobile phone application that is easily applicable in the field since it allows to obtain, immediately, the desired variables, as well as the F-V profile of each athlete. The results of Balsalobre-Fernández et al. (2015) study showed that CMJ height can be easily, accurately and reliably evaluated using a specially developed iPhone 5 s app which can help coaches to monitor the vertical jump ability of their athletes in a valid and economic way. Therefore, "all the important mechanical outputs of jumping and sprinting can be derived from basic measures of body mass, lower-limb length, jump height, and distance–time or speed–time measurements only" (Morin & Samozino, 2016, p. 2).

According to the investigation conducted by Balsalobre-Fernández et al. (2015) it is proved that this mobile phone application has already been used and that it is scientifically approved. A specific session of preparation to use this instrument was conducted to collect data from dancers on October 5th, 2019.

Training program structure

The main goals of the exercises included in the training program were to improve gymnasts FV-Profile and their jump height. Base and top gymnasts performed the same training program since jumping is a skill required by all gymnasts.

Throughout the nine weeks, we ensured that the environmental conditions remained stable. The training sessions were carried out in the gymnastics club without musical accompaniment and always with the correction of qualified coaches to ensure that the exercises were performed correctly. Training sessions took place on Tuesdays and Fridays between 5 p.m and twenty past 5 p.m.

Both control and intervention groups remained with their usual gymnastics training routine which also includes resistance training (without specificity for jumping ability) and a plyometric circuit (once a week). Force deficit training program designed mainly consisted of full squats, single leg squats, lunges, step ups and posteriorly evolved to burpees, unilateral jumps with obstacles, box SJ and single lunge jumps. Velocity deficit training program incorporated more ballistic exercises such as depth jumps, CMJ (10% BW), SJ with elastic band, SJ to the box and evolved to drop jumps, maximal roller push-off and bounding. Details for the percentages of body mass, in addition to sets and repetitions corresponding to each exercise, are detailed in attachment 1 and 2.

Before the training sessions, gymnasts performed their usual training warm-up. Jimenez-Reyes et al. (2016) suggested periods between 6 to 12 weeks to promote maximum neuromuscular adaptations. A 9-week length was stablished considering this recommendation and the periodization of the main coach.

The 9-week training program was divided into four phases. The first phase (week 1 and 2) aimed to develop the correct exercise technique. In the second phase (week 3 and 4), the training volume increased gradually. Then, in the third phase (weeks 5 and 6) we focused on progressively increasing the exercises difficulty through more unilateral and ballistic movements. Finally, in phase four (weeks 7 to 9), technical execution and the recruitment of fast fibers were privileged, using the most advanced exercises of the entire program.

The main goal was providing the gymnasts with short time cycles to promote a continuous and positive adaptation, which means that at every two weeks, gymnasts would experience a progressive improvement.

Since the sample was constituted by youth and adult athletes, the training program was adapted according to the different ages and ethical matters, considering factors such as external loads, volume, repetitions, sets and rest intervals. Exercises difficulty was adapted to gymnasts' capacities through the use of some additional load relatively to body weight and different boxes' heights. Jimenez-Reyes et al. (2016) exercise recommendations were considered. Recommendations of Faigenbaum et al. (2009) were also considered relatively to the training frequency, number of repetitions, sets and recovery intervals for younger gymnasts. Finally, the NSCA's recommendation for exercises classified as strength and power speed for young people was used as a reference.

Survey regarding front tuck execution perception

After the training program application, it was important to measure the transfer to Acrobatic Gymnastics specificity through the evaluation of a gymnastics individual element. According to Prassas et al. (2006), most research in floor exercises examines the take-off and landing characteristics of various types of somersault, mostly backward. Despite this, we selected the front tuck considering that athletes should be capable of executing the element safely and without any assistance. We thought that if jumping performance was developed throughout the training program, there would be a positive transfer for this element and the technique will approach the optimal performance criteria.

Warming up and execution of a few front tucks were allowed before recording. The gymnastics element documentation took place before and after the training program application with a SONY Hdrcx240 video camera and each gymnast was fully informed. In addition, all gymnasts delivered a declaration of consent regarding the "Declaration of Helsinki" of the World Medical Association (Helsinki 1964; Tokyo 1975; Venice 1983; Hong Kong 1989; Somerset West 1996 and Edinburgh 2000) presented in attachments 3 and 4. Changes in the element's height were the main factor to be assessed, even though the technique is always very relevant to improve any skill. However, we intend to verify mainly if there was a development of strength and/or velocity of the lower limbs.

Six qualified judges and gymnastics coaches answered to an online survey, created in Google Forms platform. Two videos of each gymnast's front tuck were presented (six gymnasts from the intervention groups and four from the control groups were selected). Videos were numbered (1 and 2) and the gymnasts identified by letter (A-J). It was not mentioned which jump was performed before and after the intervention of the training protocol.

In the following table 5 are presented the questions selected:

Table 5. Survey questions regarding front tuck execution perception

Phase	Questions
Approach run and power hurdle	1. In video 1, gymnast's approach run made it possible to make a strong and fast power hurdle (near the floor), using the explosive strength of the lower limbs. 2. In video 2, gymnast's approach run made it possible to make a strong and fast power hurdle (near the floor), using the explosive strength of the lower limbs.
Direction and quality of the power hurdle	3. In video 1, the gymnast managed to execute the front tuck preparation with a strong and quick power hurdle (near the floor), using the explosive strength of the lower limbs effectively, directing the movement upwards and not forward with control of the body segments. 4. In video 2, the gymnast managed to execute the front tuck preparation with a strong and quick power hurdle (near the floor), using the explosive strength of the lower limbs effectively, directing the movement upwards and not forward with control of the body segments.
Vertical jump	5. In video 1, when the gymnast performed the vertical jump, he managed to perform a complete extension of the lower limbs and trunk, transforming the horizontal speed acquired in the approach run in height, managing to execute the element as high as possible. 6. In video 2, when the gymnast performed the vertical impulse, he managed to perform a complete extension of the lower limbs and trunk, transforming the horizontal speed acquired in the approach run in height, managing to execute the element as high as possible.

Tucked position	7. In video 1, during vertical drive and at the final moment of the full extension of the body, the gymnast managed to quickly acquire the tucked position. 8. In video 1, during vertical drive and at the final moment of the full extension of the body, the gymnast managed to quickly acquire the tucked position.
Opening ("kick-out") and landing	9. In video 1, jump height enabled the gymnast to perform the opening of the body allowing a smooth landing, with good cushioning showing body control. 10. In video 2, jump height enabled the gymnast to perform the opening of the body allowing a smooth landing, with good cushioning showing body control.
General impression	11. General technical impression: In your opinion, which of the front tucks was the most successful? List 3 technical aspects in order of importance that make the video you selected have been better executed than the other.

As seen in table 5, the survey was constituted by ten close-ended and one open ended-question. According to Reja et al. (2003), the participants produced a much more diverse set of answers on the open-ended question. However, these authors also stated that these questions "(…) should be more explicit in their wording (at least for Web surveys, as a self-administered mode of data collection) than close-ended questions, which are more specified with given response alternatives" (Reja et al., 2003).

In applying the survey, each criterion was assessed using a Likert scale ranging from 1 to 5. The following general word anchors were provided for scoring purposes: at the end 0 - strongly disagree and at the end 5 - completely agree.

To simplify the evaluation of the gymnastic element, we chose to divide it into different phases: 1. Approach run and power hurdle; 2. Direction of the power hurdle; 3. Vertical jump; 4. Tucked position; 5. Opening ("kick-out") and landing (table 5).

Finally, we conducted expert validation in which the survey was evaluated and tested by four specialists, three of whom were university professors with experience in this matter, international judges and elite coaches. This validation allowed us to detect errors and improving questions' structure so that the language was clear and objective.

Statistical procedures

For statistical analysis, we used the IBM SPSS Statistics 26 software. Normal distribution for the study variables was assessed with the Shapiro–Wilk test. Descriptive statistics was calculated considering the mean, minimal and maximal values and standard deviation. To determine the progress over time, we used a Mixed Anova for 2 evaluation moments for all F-V profile mechanical variables with Bonferroni adjustment and level of significance set at $P \leq 0.05$. To evaluate how anthropometric variables altered over time, a repeated measures T test was conducted since variations in these measures could affect gymnasts' jumping performance, also using a level of significance of $P \leq 0.05$.

The magnitudes of change were calculated with the effect size (ES) of Hopkins (2004). The criterion for interpreting these magnitudes was <0.2 = trivial, 0.2 to 0.6 = small, 0.6 to 1.2 =moderate, 1.2 to 2 = large, and >2.0 = very large (Hopkins et al., 2009). The probability that these differences actually exist was assessed via magnitude-based qualitative inferences (Batterham & Hopkins, 2006). Probabilities that differences were higher than, lower than, or similar to the smallest worthwhile difference were defined by the following scale: <0.5%, almost certainly not, <5%, very unlikely, <25%, unlikely, probably not, 25-75%, possibly, possibly not, >75%, likely, probably, >95%, very likely and >99.5%, almost certainly.

Finally, to measure the transference to this Gymnastics discipline, we tried to understand if jump height changed the execution perception of the front tuck. For that, expert validation and a repeated measures T test were conducted. To properly evaluate this element and to correspond to the investigation goals, evaluation criteria privilege changes in height that gymnasts were able to reach in the front tuck. We thought that a gymnast who developed strength/velocity (that was lacking initially), should be able to perform this element more effectively.

Results

Base gymnasts' groups

Results presentation is divided by gymnasts' specialty: base and top gymnasts. In the following table 6 are presented the results for anthropometric variables for base gymnasts' groups:

Table 6: Anthropometric variables from base gymnasts' groups and Intragroup Comparison

Variables	Base gymnasts Control Group (n=9)			Base gymnasts Intervention Group (n=8)		
	Pre Mean (SD)	Post Mean (SD)	P	Pre Mean (SD)	Post Mean (SD)	P
Age (years)	16.64 (2.33)	16.87 (2.33)	0.000*	19.59 (3.22)	19.83 (3.22)	0.000*
Weight (kg)	60.29 (8.63)	61.46 (7.19)	ns	65.65 (12.55)	67.97 (13.85)	0.010*
Height (cm)	167.44 (5.64)	167.56 (5.46)	ns	167.88 (6.75)	167.88 (6.75)	ns
BMI (kg/m²)	21.46 (2.62)	21.87 (2.23)	ns	23.10 (2.58)	23.91 (3.04)	0.009*
HPO (cm)	39.00 (6.06)	39.28 (6.02)	ns	37.38 (4.66)	37.63 (4.63)	ns

*Legend - *P≤0.05 = Repeated measures T Student test; BMI – Body Mass Index; HPO - Height of Push Off; ns – not significant SD – Standard deviation.*

In table 6, it is important to highlight changes in anthropometric variables over time. In base gymnasts control group, which was the youngest group, weight and height increased non significantly across time (1.17kg and 0.12cm, respectively). On the other hand, base gymnasts intervention group, which was already the oldest and heaviest group, increased their weight significantly in 2.32 kg (from 65.65 (12.55) kg to 67.97 (13.85) kg with P=0.010) and their BMI (p=0.009) but their height remained the same (167.88 (6.75) cm).

In the following table 7 the results for each F-V variable are presented for base gymnasts' groups:

Table 7. F-V profile associated variables and ES from base gymnasts' groups and Intergroup Comparison

	Base gymnasts Control Group					Individual response	Base gymnasts Intervention Group					Individual response	
Variables	**Pre Mean (SD)**	**Post Mean (SD)**	**ES Mean (SD)**	**Inference**	**Probability**	**Positive-Trivial-Negative**	**Pre Mean (SD)**	**Post Mean (SD)**	**ES Mean (SD)**	**Inference**	**Probability**	**Positive-Trivial-Negative**	**P**
CMJ (cm)	35.51 (5.02)	36.74 (5.09)	0.22 (0.40)	Small	Possibly	54-42-4	33.98 (6.96)	35.04 (8.52)	0.08 (0.16)	Small	Likely	10-89-1	0.203
F-VImb (%)	28.77 (22.16)	41.55 (14.83)	0.52 (0.61)	Small	Likely	82-15-3	50.75 (17.74)	27.00 (21.90)	-1.19 (0.40)	Moderate	Almost certainly	0-0-100	0.225
V0 (m/s)	3.31 (1.10)	3.50 (0.83)	0.15 (0.70)	Trivial	Possibly	45-36-19	3.60 (1.79)	3.23 (1.43)	-0.18 (0.27)	Trivial	Possibly	2-53-45	0.150
F0 (N/kg)	32.7 (6.51)	33.07 (7.66)	-0.10 (0.99)	Trivial	Possibly	30-28-42	34.03 (9.89)	34.17 (5.07)	0.01 (0.51)	Trivial	Possibly	25-52-23	0.295
Pmax (W/kg)	27.10 (5.36)	27.78 (2.96)	0.20 (0.68)	Small	Possibly	50-35-16	28.05 (8)	26.46 (7.53)	-0.16 (0.15)	Trivial	Possibly	0-67-33	0.249

Legend - P≤0.05 = Mixed anova, Pairwise comparisons (intergroups) pre-test and post-test between all groups; CMJ, countermovement jump; ES, effect size; F0, theoretical maximal force; F-VIMB, difference between the magnitude of the actual and optimal F-V profile for each individual; Pmax, theoretical maximal power; V0, theoretical maximal velocity.

As seen in table 7, there are no significant differences between all the groups across time. Post hoc tests showed no significant differences in F-VImb, V0, F0 and Pmax variables between groups.

Even though there are no significant differences, there are relevant variations that occurred over time. Regarding CMJ height, intervention group improved 1.14cm and control group improved 1.23cm. While the F-VImb of control base gymnasts worsened 13%, the intervention base gymnasts improved 23% with a moderate effect size of -1.19 (0.40) and a 100% probability of the training program having a negative effect in this variable. In the following figure II is presented the behavior of this variable across time.

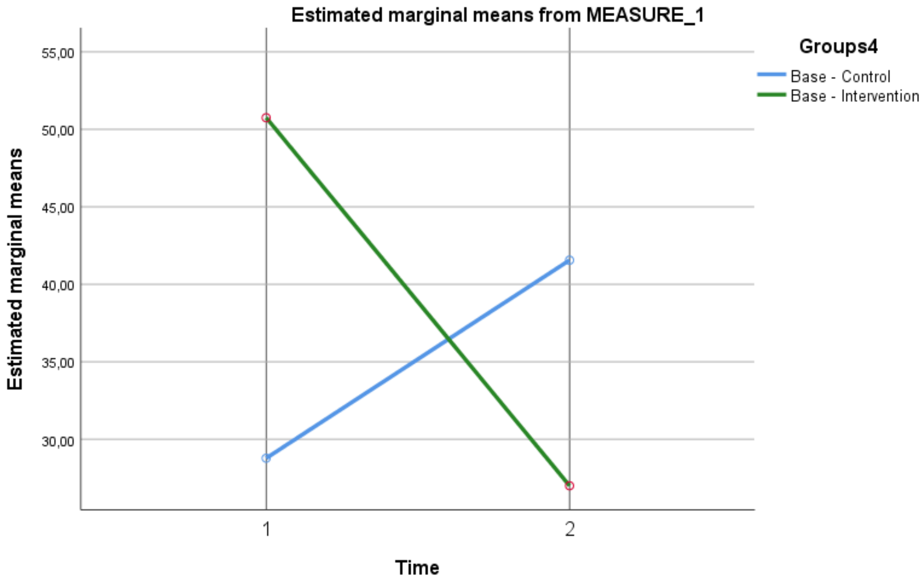

Figure II - Behavior of F-VImb variable across time in base gymnasts' groups

It is important to highlight that F-VImb values must approach value 0, meaning that our goal was to decrease (in a negative direction). In this case, intervention group F-VImb went from 50.75 (17.74) % to 27 (21.90) % approaching 0 value (as seen in figure II), reason why what appeared to be a negative effect indicates a positive outcome.

Regarding V0 and F0 variables, control group increased both variables, in contrast to the intervention group in which V0 decreased and F0 increased slightly. Regarding Pmax, it appears that there was an increase in the control group and a decrease in the intervention group.

Finally, regarding all multiple comparations, there are statistically significant differences in CMJ of control groups (between base and top gymnasts) across time (p=0.048).

Top gymnasts' groups

In the following table 8 are presented the results for anthropometric variables for top gymnasts' groups:

Table 8. Anthropometric variables from top gymnasts' groups and Intragroup Comparison

Variables	Top gymnasts Control Group (n=4)			Top gymnasts Intervention Group (n=7)		
	Pre Mean (SD)	Post Mean (SD)	P	Pre Mean (SD)	Post Mean (SD)	P
Age (years)	12.03 (1.38)	12.27 (1.38)	0.000*	14.56 (2.08)	14.79 (2.08)	0.000*
Weight (kg)	28.45 (4.64)	29.58 (5.02)	0.014*	38.54 (6.32)	40.71 (6.75)	0.000*
Height (cm)	136 (4.97)	136 (4.97)	ns	151 (7.17)	151.29 (7.48)	ns
BMI (kg/m²)	15.30 (1.37)	15.90 (1.54)	0.009*	16.79 (1.21)	17.67 (1.32)	0.000*
HPO (cm)	29.50 (3.42)	30.13 (3.84)	ns	34.21 (4.04)	34.07 (3.59)	ns

*Legend - *P≤0.05 = Repeated measures T Student test; BMI – Body Mass Index; HPO - Height of Push Off; ns – not significant; SD – Standard deviation.*

In table 8, looking at top gymnasts control group, which was the youngest group, it is possible to note that weight increased significantly across time (1.13kg with P=0.014) and height values remained the same. On the other hand, top gymnasts intervention group, which was already the oldest group, increased their weight significantly in 2.17 kg (from 38.54 (6.32) kg to 40.71 (6.75) kg with p=0.000) and their height in 0.29cm. However, this small increase in height is not significant.

In the following table 9 are presented the results for each F-V variable for top gymnasts' groups:

Table 9. F-V profile associated variables and ES from top gymnasts' groups and Intergroup Comparison

	Top gymnasts Control Group					Individual response	Top gymnasts Intervention Group					Individual response	
Variables	**Pre Mean (SD)**	**Post Mean (SD)**	**ES Mean (SD)**	**Inference**	**Probability**	**Positive-Trivial-Negative**	**Pre Mean (SD)**	**Post Mean (SD)**	**ES Mean (SD)**	**Inference**	**Probability**	**Positive-Trivial-Negative**	**P**
CMJ (cm)	27.50 (3.42)	27.05 (3.87)	-0.10 (0.41)	Trivial	Possibly	9-61-30	29.70 (2.75)	30.56 (2.7)	0.23 (0.51)	Small	Possibly	54-38-8	0.203
F-VImb (%)	44.50 (28.57)	32.00 (23.5)	0.78 (1.48)	Moderate	Likely	79-10-11	32.00 (13.02)	33.14 (16.35)	0.08 (1.14)	Trivial	Possibly	42-25-33	0.225
V0 (m/s)	2.81 (1.95)	2.95 (0.89)	-0.35 (0.75)	Small	Possibly	9-25-66	2.89 (0.42)	2.61 (0.6)	-0.57 (0.68)	Small	Likely	3-13-84	0.150
F0 (N/kg)	30.77 (6.93)	32.40 (3.09)	0.17 (1.05)	Trivial	Possibly	48-29-23	32.35 (3.88)	37.94 (9.35)	1.29 (1.45)	Large	Likely	90-5-5	0.295
Pmax (W/kg)	27.60 (10.33)	23.45 (5.07)	-0.29 (0.59)	Small	Possibly	7-30-53	23.07 (1.56)	23.67 (2.05)	0.05 (0.74)	Trivial	Possibly	35-38-27	0.249

Legend - P≤0.05 = Mixed anova, Pairwise comparisons (intergroups) pre-test and post-test between all groups; CMJ, countermovement jump; ES, effect size; F0, theoretical maximal force; F-VIMB, difference between the magnitude of the actual and optimal F-V profile for each individual; Pmax, theoretical maximal power; V0, theoretical maximal velocity.

As seen in table 9, there are no significant differences between all the groups across time. Post hoc tests showed no significant differences in F-VImb, V0, F0 and Pmax variables between groups. Although there are no significant differences, there are relevant changes over time.

Regarding CMJ height, control group decreased slightly (from 27.50cm to 27.05cm), while the intervention group improved 0.86 cm. F-VImb of control group improved 12% and the intervention group improved 1.14%. Regarding V0 and F0 variables, control group increased both values and intervention group decreased their velocity and increased their F0 values. In the following figure (figure III) is present the behavior of F0 variable across time in top gymnasts' groups.

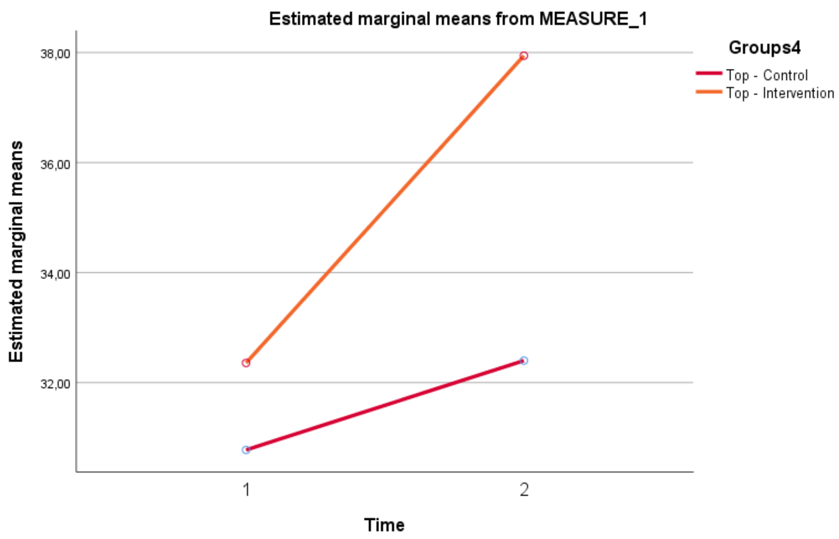

Figure III - Behavior of F0 variable across time in top gymnasts' groups

In figure III, it is possible to understand that there is a clear tendency for intervention top gymnasts F0 values to increase across time even though their F-VImb did not improved. Intervention group started with 32.35 (3.88) N/kg and post-intervention evolved to 37.94 (9.35) N/kg with a large effect size and 90% chances of a positive effect from the training program.

Finally, it appears that Pmax values decreased in the control group and increased slightly in the intervention group.

Behavior of F-V Profile across time

According to Jimenez-Reyes et al. (2016), there are 5 types of deficit: well balanced, <10%; low force–velocity deficit, 10% to 40%; and high force–velocity deficit, >40%.

In the following table 10 are presented pre and post gymnasts' F-V imbalances to understand how this variable behaved across the 9-week training program application.

Table 10. Pre and post gymnasts' F-V imbalances

Variables	Base gymnasts Control Group (n=9)	Base gymnasts Intervention Group (n=8)	Top gymnasts Control Group (n=4)	Top gymnasts Intervention Group (n=7)
Pre-intervention gymnasts' F-V imbalances	2 High force deficits (22.22%) 3 Low force deficits (33.33%) 2 Well-Balanced (22.22%) 2 Low velocity deficits (22.22%)	3 High force deficits (37.50%) 3 Low force deficits (37.50%) 2 High velocity deficits (25%)	2 High force deficits (50%) 1 Low force deficit (25%) 1 Low velocity deficit (25%)	3 High force deficits (42.86%) 3 Low force deficits (42.86%) 1 Low velocity deficit (14.29%)
Post-intervention gymnasts' F-V imbalances	5 High force deficits (55.56%) 2 Low force deficits (22.22%) 1 Low velocity deficit (11.11%) 1 High velocity deficit (11.11%)	1 High force deficit (12.50%) 4 Low force deficits (50%) 2 Well-Balanced (25%) 1 Low velocity deficit (12.50%)	2 High force deficits (50%) 1 Well-Balanced (25%) 1 Low velocity deficit (25%)	1 High force deficit (14.29%) 2 Low force deficits (28.57%) 3 Low velocity deficits (42.86%) 1 High velocity deficit (14.29%)

In table 10, it is possible to verify how gymnasts' F-V profiles evolved across time. It is possible to observe that base gymnasts' control group increased the high force deficit percentage from 22.22% to 55.56% and the 22.22% of well-balanced gymnasts vanished and a 11.11% of high velocity deficit appeared. On the other hand, base gymnasts' intervention group decreased their percentage of high force deficit from 37.50% to 12.50%, gained 25% of well-balanced gymnasts and lost their 25% of initially high velocity deficit.

Regarding top gymnasts' groups, control group maintained practically the same tendency, except that the 25% of low force deficit vanished and a 25% of well-balanced appeared. Intervention group decreased their high force deficit percentage from 42.86% to 14.29% and their low force deficit from 42.86% to 28.57%. Finally, a percentage of 14.29% of high velocity deficit appeared.

Transfer to Acrobatic Gymnastics' specificity

In the following table (table 11) the pretest and posttest means (SD) and the results of survey answers' quantitative analysis are presented:

Table 11. Survey answers' quantitative analysis

Groups	Pretest Mean (SD)	Posttest Mean (SD)	P
Control group (n=4)	3.57 (0.58)	3.57 (0.51)	0.995
Intervention group (n=6)	2.83 (0.48)	3.66 (0.43)	0.013*

Legend - P≤0.05 - Repeated measures T test.

As seen in table 11, there are significant differences in the intervention group (p=0.013), indicating that jump height changed the execution perception of the front tuck of the intervention group after the training program.

Open-ended question qualitative analysis

In addition to analyzing the quantitative questions, it was also relevant to analyze the open-ended question to understand judges' points of view regarding the technical aspects that possibly improved after the training program. Judges and coaches answered the following question:

General technical impression: In your opinion, which of the front tucks was the most successful? List 3 technical aspects in order of importance that make the video you selected have been better executed than the other.

In the following table (table 12) is presented the analysis of the open-ended question of the survey:

Table 12. Open-ended question qualitative analysis

Technical aspects	Accounting	Interpretation
Faster approach run and power hurdle	In 74 technical aspects mentioned, 22 reported that from one video to another, there were improvements in the approach run and power hurdle.	This value represents 28.78% of the total answers.
Better impulse of lower limbs and direction of the power hurdle (verticality)	In 74 technical aspects mentioned, 26 reported that from one video to another, there were improvements in the impulse of lower limbs and direction of the power hurdle.	This value represents 35.14% of the total answers.
Vertical jump (better extension of body segments, higher ROM, higher jump)	In 74 technical aspects mentioned, 16 reported from one video to another, there were improvements in vertical jump.	This value represents 21.62% of the total answers.
Tucked position (faster)	In 74 technical aspects mentioned, 9 reported that from one video to another, there were improvements in the tucked position.	This value represents 12.16% of the total answers.
Opening ("kick-out") and landing (body segments control)	In 74 technical aspects mentioned, 2 reported that from one video to another, there were improvements in the tucked position.	This value represents 2.70% of the total answers.

Table 12 shows the technical aspects most mentioned by the judges and coaches in the open-ended questions analysis as those that contributed most to the improvement of the gymnastics element. When comparing videos of the gymnastics element executed pre- and post-intervention, responders identify the aspects that justified why a certain element was better executed than the other. According to the answers, the most mentioned aspects were the impulse of lower limbs and direction of the power hurdle (35.14%), followed by the approach run and power hurdle (28.78%) and the vertical jump (21.62%). These results suggest that these 3 aspects of the front tuck benefited most of the exercises, which means that they obtained the major transfer from the training program. The less referred phase by the responders was the opening and landing (only 2.06%).

Discussion

To understand and interpret our results, it is important to considerer all the variables of the investigation and that each athlete will have optimal individual values. For example, velocity values cannot be examined accurately out of the absolute value, they should be interpreted considering the ideal individual value for each athlete. For this reason, we must consider the relations stablished between all F-V profile associated variables to understand why different groups improved different variables. For example, an improvement in F-VImb can be supported by an increase in some variables in prejudice of others depending on the type of athlete and sports. In this discussion, we will try to stablish this type of interactions to understand the behavior of this specific context of Acrobatics Gymnastics with these high-performance athletes.

Kraemer & Newton (2000) results can help to understand our findings since if a component is already highly developed (e.g., strength at low velocities), then greater attention to other components (e.g., plyometric training for stretch shortening cycle performance) is more rewarding. Since the training program emphasized the least developed component (F0 or V0), our results indicate the existence of these type of relationships in intervention groups, mainly a decreased V0 to allow F0 to increase. In this matter, to find balance, F0 and V0 should increase and decrease inversely since the force that a muscle can develop concentrically decreases as the velocity of movement increases (Kraemer & Newton, 2000). The same authors explained these reversed relationships found in our investigation: when squatting the maximal amount of weight possible, the weight will be moved very slowly; if the weight decreases in half, it will be lifted at a faster velocity since maximal shortening velocity occurs when no resistance is being moved. This velocity is determined by the maximal rate at which cross bridges can be formed and broken with the actin active sites (Kraemer & Newton, 2000). Since there is, for each individual, an optimal F-V profile that maximizes ballistic performance and represents the optimal balance between strength and speed qualities for these movements (Samozino et al., 2014; Samozino et al., 2012), there is only one combination that allows each athlete to reach their maximum potential.

Regarding unclear results in Pmax in our intervention groups (a slight decrease in bases gymnasts and a slight increase in tops gymnasts), Jimenez-Reyes et al. (2016, p. 1) results showed "(…) unclear or small changes in Pmax (−0.40 ± 8.4% and +10.5 ± 5.2%, respectively)". In fact, Pmax represents the combination between F0 and V0 and for the same Pmax value, there are multiple possible combinations of this variables. What is already known is that strength and power are related but this relationship decreases as the athletes strength base increases until reaching their genetic maximum (Kraemer & Newton, 2000). Our results support these authors statement that when an athlete presents a more highly trained strength component, his training should prioritize specific power training to maximize power development.

These aspects can explain why these results cannot be interpreted considering only the absolute values and will be considered throughout the discussion. To attend to both specialties in this gymnastics discipline, the discussion will be divided between base and top gymnasts' groups.

Base gymnasts' groups

Starting with base gymnast specialty, our results showed a tendency for intervention group F-V profiles to approach their optimal values, contrary to the control group. In addition, while their V0 lowered, F0 had a slight increased and Pmax decreased. On the other hand, control group worsened their F-VImb considerably while their V0 and F0 slightly increased and their Pmax increased.

We can detect a positive effect of the training program in this group since it was able to provide a balance between F0 and V0 variables (V0 decreased to allow F0 to increase). Also, while Pmax decreased in the intervention group, it increased in the control group. Although Pmax interpretation is very delicate, this might be another aspect to consider when interpreting the substantial improvement in the F-VImb of the intervention group.

Regarding CMJ variable, control group jumped 35.51 (5.02) cm and progressed to 36.74 (5.09) cm through their habitual gymnastics training. On the other hand, base gymnasts from intervention group jumped 33.98 (6.96) cm and after the training program evolved to 35.04 (8.52) cm. It is possible to identify improvements of 1.23cm and 1.14cm in these groups, respectively, meaning that both base gymnasts groups improved their jump height. Even though gymnasts were randomly divided in control and intervention groups, control gymnasts ended up having younger and lighter gymnasts, which allowed the intervention base (older, heavier and taller) to improve their jumping ability, considering that before the intervention they already presented a lower jump height.

In addition to initially being heavier, they increased their weight significantly (2.32kg, corresponding to p=0.010) and maintained their height after the training program application. In this sense, jumping performance was expected to decrease. It is possible to consider that our training program might have mitigated the negative effects of gymnasts' increased weight since they managed to improve their jump height besides this aspect.

Secomb et al. (2017) results can also sustain these small improvements in jump height. In their investigation, even though resistance training resulted in significant changes in lower body force producing capabilities and gymnastics and plyometric training evoked significant changes in the muscle structure and eccentric leg stiffness qualities, this did not translate to enhanced jumping performance. Our results are related to Kraemer & Newton (2000) considerations regarding the greater difficulty in producing training adaptations in maximal power activities such as vertical jump as the level of the athlete's ability and depth of training background increases. Häkkinen (1989 cit by Kraemer & Newton, 2000) investigation also highlight the lack of improvement in power performance, particularly in athletes who have already developed a strength training base even though heavy resistance training increased maximum strength training and the highest point of the force-time curve in their study.

We believe this authors evidence sustain our results since our sample is constituted by first division and elite athletes. More specifically, control group presented 7.67 (3.08) years of practice and the intervention group 9.13 (3.94) years. These athletes have 6 (0.00) training sessions per week, train 4.78 (0.44) (control group) and 5 (0.00) (intervention group) hours per day. Both groups present a substantial training background.

Top gymnasts’ groups

Regarding top specialty, results showed that the F-VImb of the intervention group increased 1.13% while V0 decreased, F0 increased considerably and Pmax increased. On the other hand, control group improved their F-VImb considerably while their V0 decreased, F0 increased and Pmax decreased. It was also possible to understand that there is a clear tendency for intervention F0 values to increase across time even though their F-VImb did not improved.

It is important to highlight that base and top gymnasts train together, but each perform a specific type of training. In this discussion, it will be important to considerer the differences between these two types of gymnasts.

In Acrobatic Gymnastics, age groups were stablished to include one younger and one to three older gymnasts, depending on the constitution of the pair/group. This allows the base gymnast to support the top gymnast safely, since “(…) each of the individual gymnast's size and skill are used to complement each other” (Fédération Internationale de Gymnastique, 2017-2020). Consequently, top gymnasts are younger (control group with 12.03 (1.38) years old and intervention group with 14.56 (2.08) years old) than base gymnasts (control group with 16.64 (2.33) years old and intervention group with 19.59 (3.22) years old); lighter (control group weighing 28.45 (4.64) kg and intervention group 38.54 (6.32) kg) than base gymnasts (control group weighing 60.29 (8.63) kg and intervention group 65.65 (12.55) kg) and smaller (control group measuring 136 (4.97) cm and intervention group 151 (7.17) cm) than base gymnasts (control group measuring 167.44 (5.64) cm and intervention group 167.88 (6.75) cm).

Since jumping and bouncing are some of the crucial skills that gymnasts have to acquire at early ages (Marina & Jemni, 2014), to support the small improvements in CMJ height and F-VImb it is important to highlight that top gymnasts represent the most unpredictable group since they are in constant transformation. Their height, weight, maturation state and motor coordination are constantly changing and evolving, which creates some constraints in investigation (reason why there are limited studies with this age group). Our results are related to Lloyd et al. (2012 cit. by Secomb et al., 2017) investigation regarding the specific and typically varying adaptations to strength and plyometric training by adolescents.

Even though top gymnasts represent an instable group, this investigation supports Marina & Jemni (2014) whereas " (…) natural growth, development, and maturation typically observed during prepubertal and pubertal ages, with the additive effect of high training volume per week, should increase plyometric performance" (Marina & Jemni, 2014, p. 1023) since in our investigation the intervention group increased their jump height, from 29.70 (2.75) cm to 30.56 (2.70) cm, while control group decreased from 27.50 (3.42) cm to 27.05 (3.87) cm.

Although there are no significant differences in jump height, it is important to consider that there were significant increases in both groups weight across time. More specifically, control group, which was the youngest group, increased 1.13kg with P=0.014 and height values remained the same. On the other hand, intervention group, which was already the oldest group, increased their weight significantly in 2.17 kg (from 38.54 (6.32) kg to 40.71 (6.75) kg)) with p=0.000) and their height in 0.29cm (not significant). Regarding intervention gymnasts, even though their F-VImb did not improved, their weight increased most across time and the fact that they were the most instable group, they managed to increase their jump height by 0.86cm nevertheless.

For these reasons, Marina & Jemni (2014) considerations regarding the effectiveness of a combination of heavy resistance training with high impact plyometric jumps in prepubertal gymnasts, despite their initial high level of physical conditioning applied to the present investigation.

Training program considerations

Newton et al. (1999) results suggest that increased overall force output during jumping and increased rate of force development were the main contributors to the increased jump height. In addition, Kraemer & Newton (2000) refer that these results lend support to the effectiveness of ballistic resistance training for improving maximal power production in elite athletes. To support our program training structure choice, it is important to refer that our main priority was to improve gymnasts' F-VImb and jumping performance through the development of their RFD, meaning that muscle must apply as much force as possible in a short period of time (Kraemer & Newton, 2000). The same authors refer that an activity during which the athlete attempts to develop force rapidly (e.g., maximal power jump training with light loads) increases an athlete's ability to increase force output at a fast rate.

Gymnasts require, from an early age, the proper strength/power profile to learn new target skills, beyond the habitual everyday skill or technical training. Definitely, gymnastics profile require high power outputs (Marina & Jemni, 2014), only possible through specialized power training complemented with high force production (Kraemer & Newton, 2000). Since our sample presented higher deficits pre-intervention, our investigation findings support these authors, addressing coaches particularly, showing that performing gymnastic skills alone does not allow gymnasts to obtain the level of strength and power precisely required for their correct execution.

Force and velocity deficit

To attend gymnastics strength/power profile requirements, for the force deficit gymnasts, we decided to apply a different approach where resistance training was combined with plyometrics to increase their power output (Bauer et al. (1990); Blakey & Southard (1987) and Clutch et al. (1983)). Also, Adams et al. (1992) highlight that this is perhaps a greater stimulus to maximal power production than either weight or plyometric training alone. Even though these findings highlight the multifaceted nature of power performance, with a mixed training methods approach being most effective as it develops more components of muscle power (Kraemer & Newton, 2000), the shift from force to plyometrics exercises in force deficit group can explain why base gymnasts group did not improved significantly they F0 values. By removing the external load in the last four weeks of the training program, force development was not stimulated, which indicates that gymnasts with force deficit were probably developing more velocity rather than force.

Regarding velocity deficit, our aim was to consider Häkkinen (1989 cit. by Kraemer & Newton, 2000) recommendations. The author stated that if the athletes already have an adequate level of strength, then the increase in maximal power performance in response to traditional strength training is poor and, more specific power training programs for the sport (e.g., higher speed exercises, plyometrics, medicine ball training, Olympic pulls) are required to further improve maximal power output in a given movement. We selected exercises with a progressive level of difficulty to promote specific adaptations in gymnasts' jumping performance.

Specificities regarding the periodization phase, age and level of gymnasts

As explained in sample characterization, training program was applied after the European Championship, meaning that gymnasts were in a special transition period followed by a specific preparation and a pre-competitive period. Gymnasts returned from the most important competition of the sports season and maintained their training routine with one month of lower training volume to recover from the competition. After this period, volume and intensity increased progressively (specific preparation) until another competition which took place in the week following the end of the training program application (pre-competitive period).

We believe that studies including this specific population regarding not only elite athletes, but also acrobatic gymnasts consist in an important contribution for scientific knowledge development and for coaches and gymnastics community all over the world. The inclusion of a special transition period allowed us to interpret our results with a contextualization of the environment evolving gymnasts. We believe that scientific research should always consider these aspects since they interfere with gymnasts' progress. Considering that intervention groups had significantly increased their weight across the training program and that they went through this active recovery period, we believe that our investigation helped to mitigate all of these negative effects since there were improvements in F-V profile associated variables as already described. Even thought there were positive outcomes from our investigation, it is reasonable to consider that probably 2-week cycles were not enough to promote a more solid adaptation in this conditioning level in this gymnastics discipline.

When observing pre and post values without consider gymnasts' context, improvements in jump height seem trivial. This aspect is highlighted by Wilson et al. (1997 cit by Kraemer & Newton, 2000) regarding diminished returns principle as the possible explainable cause, whereby initial improvements in muscular function are easily attained and further improvements are progressively harder to achieve. Our investigation supports these authors regarding training within a sports-specific conditioning program.

Regarding youth training, our results are in agreement with Secomb et al. (2017) regarding adolescents involvement in structured strength and conditioning training, as opportunities for enhanced performance qualities may be missed if natural maturation is relied upon during this time. This evidence supports the importance of these types of training for adolescent athletes, even though there are still some ethical apprehensions in scientific community. Our investigation results also indicate the importance of development of muscle power, not only in elite adult athletes but also in child and particularly in adolescent athletes (Slimani et al., 2018) and support these authors meta-analysis' that clearly proved the general effectiveness of strength training on lower-limb muscle power in young athletes (Slimani et al., 2018). In this sense, our results also suggest that time devoted to physical condition training designed to optimize the plyometric skills of gymnasts should be increased at the expense of time spent on technical routines (Marina & Jemni (2014) and Agostini et al. (2017)).

Regarding athletes deficits, our investigation indicates that training programs should address the lacking component (force or velocity) since, according to Jimenez-Reyes et al. (2016, p. 10), "(…) an optimized and individualized training program specifically addressing the force-velocity imbalance is more efficient at improving jumping performance than a traditional resistance training common to all subjects regardless of their force-velocity imbalance and optimal force-velocity profile". Finally, when idealizing specific training programs, Kraemer & Newton (2000, p. 364) suggest that the current status of the individual is particularly important with regard to muscular strength in fast and slow muscle actions, RFD capability, stretch shortening cycle ability and intermuscular coordination and skill. These authors also mention that greatest improvements in maximal power production are obtained if a range of training methodologies is implemented that address each of these components.

Transfer to Acrobatic Gymnastics

In our investigation, there were significant differences in the front tuck execution perception in the intervention group. It was possible to find a study conducted by Hall et al. (2016) who applied a sport-specific plyometric intervention to the habitual training of youth female gymnasts which improved handspring vault performance measures and gymnasts functional power.

Harries et al. (2012) findings are related to the present investigation results regarding the sufficient evidence to conclude that resistance-training interventions can improve muscular power in adolescent athletes. According to this systematic review and meta-analysis, "(…) a positive effect on sports performance attributable to participation in resistance training was reported by almost half the included studies, however limited objective evidence to support these claims was found. Improvements in motor performance skills, such as jumping, are widely stated as indicators of improvements in sporting performance" (Harries et al., 2012, p. 1). The same authors detected a positive effect for resistance training programs on vertical jump performance (mean difference 3.08 [95% CI 1.65, 4.51], $Z = 4.23$ [$P < 0.0001$]).

As seen in open-ended analysis, when comparing videos of the gymnastics element executed pre and post-intervention, responders' refer that these 3 technical aspects were the ones where it was possible to identify greater changes across time: approach run and power hurdle improvement (aspects referring to velocity and power of both), better impulse of lower limbs (better application of explosive strength) and direction of the power hurdle (verticality) and vertical jump (better extension of body segments, higher range of motion, higher jump). It is important to note that the opening and landing aspect was only referred 2 times, meaning that athletes developed mainly a faster approach run and power hurdle, improved the application of the drive provided by the lower limbs which contributed to a more vertical power hurdle and it was also referred that in the moment of the jump, there was a better extension of the body (mainly lower limbs) which contributed to a higher and more defined front tuck.

Even though it has not been established which types of programs are most suitable for increasing muscular power and improving sporting performance in various adolescent athlete subgroups, resistance training, plyometric training, speed training or combinations of these training modalities all have the potential to improve muscular power in adolescent athletes (Harries et al., 2012) as seen in our findings. Further research is required, in the absence of habitual sporting practice, to determine the specific effects of these training methodologies.

Once again, our results are related to Harries et al. (2012) review that has also found that improvements in motor performance skills, such as jumping, are widely considered as indicators of improvements in sporting performance and that further research investigating the association between improvements in muscular power and motor performance skills and sports performance is needed.

Conclusions

We believe that this investigation answered the problem formulated initially aiming, in a first phase, to investigate the vertical Force-Velocity profile behavior during the Counter Movement Jump of 1st division and elite Acrobatic gymnasts before and after the application of a training program during a special transition period and, in a second phase, to analyze the influence of jump height in the front tuck execution perception.

Regarding base gymnasts, we ascertained that there is a tendency for intervention group F-V profiles to approach their optimal values, contrary to the control group. While the F-VImb of the control group worsened 13%, the intervention group improved 23% with a moderate effect size of -1.19 (0.40) and a 100% probability of the training program having a negative effect in this variable (since our goal was to approach 0 value). Regarding CMJ variable, it was possible to identify improvements of 1.23cm (control group) and 1.14cm (intervention group), meaning that both base gymnasts groups improved their jump height. In addition to base gymnasts from intervention group initially being heavier and presenting a lower jump height than the control group, intervention group increased their weight significantly (2.32kg, corresponding to $p=0.010$) and maintained their height after the training program application. In this sense, jumping performance was expected to decrease. It is possible to conclude that our training program might have mitigate the negative effects of gymnasts' increased weight since they improved their jump height, nevertheless.

Regarding top gymnasts, even though they did not improve their F-VImb, there is a clear tendency for intervention top gymnasts F0 values to increase across time (from 32.35 (3.88) N/kg and post-intervention evolved to 37.94 (9.35) N/kg) with a large effect size and 90% chances of a positive effect from the training program. Intervention group increased their jump height, from 29.70 (2.75) cm to 30.56 (2.70) cm, while control group decreased from 27.50cm to 27.05cm. Since intervention group F-VImb did not improved, their weight increased the most across time and the fact that they were the most instable group, jump height would be expected to decrease but it increased 0.86cm nevertheless.

Finally, jump height changed the front tuck execution perception of the intervention group. We concluded that the 9-week training program was effective in improving specific jumping ability of this gymnastics discipline.

Regarding the inclusion of a special transition period and gymnasts' increased weight, it is reasonable to conclude that our 9-week training program might have mitigate these negative effects since gymnasts managed to improve their jump height, nevertheless.

Acrobatic Gymnastics does not have a vast development around scientific research due to being a recent sport. Consequently, this thesis sought to develop a new subject in this gymnastics discipline and to contribute to the improvement of scientific knowledge in Acrobatic Gymnastics, thus emerging as an innovation in this area.

Limitations and Future Research

As limitations, some difficulties arose in finding scientifically and objective grounded guidelines regarding youth training recommendations. To overcome this obstacle, we consider the recommendations of Faigenbaum et al. (2009) since that was the most objective study that it was possible to find. The main limitation consisted in the ethical restraints existing when conducting investigation with youth, mainly in the inclusion of exercises with external load. The ethical restraints limited our study since we always felt the need to protect our younger participants since they are the most unpredictable group: their height, weight, maturation state and motor coordination is constantly changing and evolving.

Another limitation was caused by the difficulty in assessing first division and elite athletes. Consequently, the sample does not have the desirable number of subjects and it was not possible to conduct control evaluations between each training phase since these athletes did not have time to spare to conduct more than 2 evaluations.

For future research, we suggest using a larger sample to make it more representative, a larger number of data as this would reduce the risk of bias in the investigation and more evaluation moments (between each variation in the training program) to control athletes' improvements across time.

Finally, there are only a few studies conducted in Acrobatic Gymnastics. We could not find studies regarding Force-Velocity profile in this sport, which means that we did not have specific information in the literature to compare and relate with our results. Consequently, we believe that our investigation is a contribution to improve coaches' practices and to increase the scientific knowledge concerning this gymnastics discipline.

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Attachments

Attachment 1: Force deficit: 9-week training program

Rest between exercises: 1:30 minutes

Rest between sets: 30 seconds

Phase 1: week 1 and 2				
Age groups	**Specialty**	**Exercises**		
		Full Squat[1]	**Single leg squat[1]**	**Step up[1]**
Youth	Top	BW	BW	BW: 47cm
	Base	60% BW	BW	BW: 50cm
Junior	Top	BW	BW	BW: 50cm
	Base	60% BW	BW	BW: 65cm
Senior	Top	30% BW	BW	BW: 65cm
	Base	60% BW	BW	BW: 75cm
Sets and repetitions		**3x10[2]**	**2x10[2]**	**2x10[2]**

(1) Jimenez-Reyes et al. (2016); (2) Faigenbaum et al. (2009)

Phase 2: week 3 and 4					
Age groups	**Specialty**	**Exercises**			
		Full Squat[1]	**Lunges**	**Single leg squat[1]**	**Step up[1]**
Youth	Top	BW	BW	BW	BW: 47cm
	Base	60% BW	30-40% BW	BW	BW: 50cm
Junior	Top	BW	BW	BW	BW: 50cm
	Base	60% BW	30-40% BW	BW	BW: 65cm
Senior	Top	30% BW	BW	BW	BW: 65cm
	Base	60% BW	30-40% BW	BW	BW: 75cm
Sets and repetitions		**3x10[2]**	**3x10 each leg[2]**	**2x10[2]**	**2x10[2]**

(1) Jimenez-Reyes et al. (2016); (2) Faigenbaum et al. (2009)

Phase 3: week 5 and 6					
Age groups	**Specialty**	**Exercises**			
		SJ to the Box[1]	**Single leg jumps with cones[1]**	**Burpees[1]**	**Lunges step ups[1]**
Youth	Top	BW: 47cm	BW	BW	BW
	Base	BW: 50cm	BW	BW	BW
Junior	Top	BW: 50cm	BW	BW	BW
	Base	BW: 65cm	BW	BW	BW
Senior	Top	BW: 65cm	BW	BW	BW
	Base	BW: 75cm	BW	BW	BW
Sets and repetitions		**3x8[2]**	**3x6[3]**	**3x6[3]**	**3x8 each leg[2]**

(1) Jimenez-Reyes et al. (2016); (2) Faigenbaum et al. (2009); (3) Dowse et al. (2017)

Phase 4: week 7 to 9					
Age groups	**Specialty**	**Exercises**			
		Russian squat[1]	**Single leg jumps with obstacles[1]**	**Burpees[1]**	**Box lunge jumps[1]**
Youth	Top	BW	BW	BW	BW
	Base	BW	BW	BW	BW
Junior	Top	BW	BW	BW	BW
	Base	BW	BW	BW	BW
Senior	Top	BW	BW	BW	BW
	Base	BW	BW	BW	BW
Sets and repetitions		**3x6[2]**	**3x6[2]**	**3x6[2]**	**3x6[2]**

(1) Jimenez-Reyes et al. (2016); (2) Dowse et al. (2017)

Attachment 2: Velocity deficit: 9-week training program

Rest between exercises: 1:30 minutes

Rest between sets: 30 seconds

Phase 1: week 1 and 2					
Age groups	**Specialty**	**Exercises**			
		Squat jump[1]	**CMJ (10% BW)[1]**	**Squat with elastic band[1]**	**Box lunge jumps[1]**
Youth	Top	BW	10% BW	Light	BW
	Base	BW	10% BW	Medium	BW
Junior	Top	BW	10% BW	Light/Medium	BW
	Base	BW	10% BW	Medium/Hard	10-15% BW
Senior	Top	BW	10% BW	Medium	BW
	Base	BW	10% BW	Hard	10-15% BW
Sets and repetitions		**3x8[2]**	**3x8[2]**	**3x6[3]**	**3x6[3]**

(1) Jimenez-Reyes et al. (2016); (2) Faigenbaum et al. (2009); (3) Dowse et al. (2017)

Phase 2: week 3 and 4							
Age groups	**Specialty**	**Exercises**					
		Depth jump[1]	**Squat jump[1]**	**CMJ (10% BW)[1]**	**SJ to the box[1]**	**Squat jump with elastic band[1]**	**Box lunge jumps[1]**
Youth	Top	BW: 47cm	BW	10% BW	BW: 47cm	Light	BW
	Base	BW: 50cm	BW	10% BW	BW: 50cm	Medium	BW
Junior	Top	BW: 50cm	BW	10% BW	BW: 50cm	Light/Medium	BW
	Base	BW: 65cm	BW	10% BW	BW: 65cm	Medium/Hard	10-15% BW
Senior	Top	BW: 65cm	BW	10% BW	BW: 65cm	Medium	BW
	Base	BW: 75cm	BW	10% BW	BW: 75cm	Hard	10-15% BW
Sets and repetitions		**3x8[2]**	**3x8[2]**	**3x8[2]**	**3x6[3]**	**3x6[3]**	**3x6[3]**

(1) Jimenez-Reyes et al. (2016); (2) Faigenbaum et al. (2009); (3) Dowse et al. (2017)

Phase 3: week 5 and 6					
Age groups	**Specialty**	**Exercises**			
		Maximal roller push-off[1]	**CMJ with arms[1]**	**Bounding with medicine ball[1]**	**Vertical jump with elastic band[1]**
Youth	Top	BW	BW	BW	Light
	Base	BW	BW	BW	Medium
Junior	Top	BW	BW	BW	Light/Medium
	Base	BW	BW	BW	Medium/Hard
Senior	Top	BW	BW	BW	Medium
	Base	BW	BW	BW	Hard
Sets and repetitions		**3x6[2]**	**3x6[2]**	**3x6[2]**	**3x5[2]**

(1) Jimenez-Reyes et al. (2016); (2) Dowse et al. (2017)

Phase 4: week 7 to 9					
Age groups	**Specialty**	**Exercises**			
		Maximal roller push-off[1]	**CMJ with arms[1]**	**Drop jump[1]**	**Boundings with medicine ball[1]**
Youth	Top	BW	BW	BW: 47cm	BW
	Base	BW	BW	BW: 50cm	BW
Junior	Top	BW	BW	BW: 50cm	BW
	Base	BW	BW	BW: 65cm	BW
Senior	Top	BW	BW	BW: 65cm	BW
	Base	BW	BW	BW: 75cm	BW
Sets and repetitions		**3x6[2]**	**3x6[2]**	**3x6[2]**	**3x6[2]**

(1) Jimenez-Reyes et al. (2016); (2) Dowse et al. (2017)

Attatchment 3: Declaration of consent for minors

U.PORTO
FACULDADE DE DESPORTO
UNIVERSIDADE DO PORTO

DECLARAÇÃO DE CONSENTIMENTO

Considerando a "Declaração de Helsínquia" da Associação Médica Mundial (Helsínquia 1964; Tóquio 1975; Veneza 1983; Hong Kong 1989; Somerset West 1996 e Edimburgo 2000)

Estudo: Efeito de nove semanas de treino baseado no perfil ótimo de força-velocidade durante o salto vertical em ginastas de 1ª divisão e elite de Ginástica Acrobática

Os objetivos deste estudo consistem, numa primeira fase, em traçar o perfil de força-velocidade de praticantes de Ginástica Acrobática com o intuito de compreender os défices de força ou velocidade existentes. Numa segunda fase, aplicaremos um programa de treino realizado dentro do horário normal dos treinos (com a duração de apenas 15 a 20 minutos, duas vezes por semana) com o objetivo de desenvolver a capacidade de impulsão vertical em cada um dos ginastas de acordo com o seu défice individual e, consequentemente, conduzir à aproximação do perfil de força-velocidade ideal para cada um dos ginastas. O programa de treino será implementado num momento favorável da época de acordo com o planeamento do treino de forma a não causar qualquer tipo de transtorno ao nível da participação em competições e respetiva gestão da fadiga.

É expectável que, após a realização do plano de treino, os ginastas melhorem a sua capacidade de impulsão vertical e que ocorra um transfere para a modalidade que praticam. Este estudo permitirá compreender se os exercícios selecionados são eficazes e se estão adaptados aos défices dos ginastas. Consequentemente, contribuirá para o controlo do treino e posterior melhoria das práticas dos treinadores de Ginástica Acrobática.

Este trabalho será desenvolvido pela investigadora Isaura Leite, aluna do Mestrado em Treino de Alto Rendimento Desportivo da Faculdade de Desporto da Universidade do Porto sob a orientação da Professora Doutora Lurdes Ávila Carvalho e Professor Doutor Filipe Conceição.

Eu, abaixo-assinado, (nome completo) ____, responsável pela ginasta, (nome completo) ____ compreendi a explicação que me foi fornecida acerca da investigação que se tenciona realizar. Foi-me dada a oportunidade de fazer as perguntas que julguei necessárias e, no caso de as ter feito, de todas obtive resposta satisfatória.

Tomei conhecimento de que, de acordo com as recomendações da declaração de Helsínquia, a informação ou explicação que me foi prestada versou os objetivos, os métodos, os benefícios previstos, os riscos potenciais e o eventual desconforto. Além disso, foi-me afirmado que tenho o direito de recusar a todo o tempo a sua participação no estudo.

Por isso, concordo que seja aplicado o método ou o inquérito proposto pelo investigador.

Data: _________/_________/_________

Assinatura do Encarregado de Educação: ____

O Investigador responsável

Nome: Isaura Leite

Telemóvel: 918049253

E-mail: isaura_alexandra@hotmail.com

Assinatura: ____

Attatchment 4: Declaration of consent for adults

U.PORTO

FACULDADE DE DESPORTO
UNIVERSIDADE DO PORTO

DECLARAÇÃO DE CONSENTIMENTO

Considerando a "Declaração de Helsínquia" da Associação Médica Mundial (Helsínquia 1964; Tóquio 1975; Veneza 1983; Hong Kong 1989; Somerset West 1996 e Edimburgo 2000)

Estudo: Efeito de nove semanas de treino baseado no perfil ótimo de força-velocidade durante o salto vertical em ginastas de 1ª divisão e elite de Ginástica Acrobática

Os objetivos deste estudo consistem, numa primeira fase, em traçar o perfil de força-velocidade de praticantes de Ginástica Acrobática com o intuito de compreender os défices de força ou velocidade existentes. Numa segunda fase, aplicaremos um programa de treino realizado dentro do horário normal dos treinos (com a duração de apenas 15 a 20 minutos, duas vezes por semana) com o objetivo de desenvolver a capacidade de impulsão vertical em cada um dos ginastas de acordo com o seu défice individual e, consequentemente, conduzir à aproximação do perfil de força-velocidade ideal para cada um dos ginastas. O programa de treino será implementado num momento favorável da época de acordo com o planeamento do treino de forma a não causar qualquer tipo de transtorno ao nível da participação em competições e respetiva gestão da fadiga.

É expectável que, após a realização do plano de treino, os ginastas melhorem a sua capacidade de impulsão vertical e que ocorra um transfere para a modalidade que praticam. Este estudo permitirá compreender se os exercícios selecionados são eficazes e se estão adaptados aos défices dos ginastas. Consequentemente, contribuirá para o controlo do treino e posterior melhoria das práticas dos treinadores de Ginástica Acrobática.

Este trabalho será desenvolvido pela investigadora Isaura Leite, aluna do Mestrado em Treino de Alto Rendimento Desportivo da Faculdade de Desporto da Universidade do Porto sob a orientação da Professora Doutora Lurdes Ávila Carvalho e Professor Doutor Filipe Conceição.

Eu, abaixo-assinado, (nome completo) ____, compreendi a explicação que me foi fornecida acerca da investigação que se tenciona realizar. Foi-me dada a oportunidade de fazer as perguntas que julguei necessárias e, no caso de as ter feito, de todas obtive resposta satisfatória.

Tomei conhecimento de que, de acordo com as recomendações da declaração de Helsínquia, a informação ou explicação que me foi prestada versou os objetivos, os métodos, os benefícios previstos, os riscos potenciais e o eventual desconforto. Além disso, foi-me afirmado que tenho o direito de recusar a todo o tempo a participação no estudo.

Por isso, concordo que seja aplicado o método ou o inquérito proposto pelo investigador.

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