Individualized training based on force-velocity profiling during jumping in ballet dancers

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Abstract

Purpose: Ballet dancers are required to achieve performance feats such as exciting and dramatic elevations. Dancers with a greater jump height can perform a wider range of skills during their flight time, and implement more specific technical skills related to the aesthetic components of a dance choreography. New findings suggest the relationship between force and velocity mechanical capabilities (F-V profile) as an important variable for jumping performance. A new field method based on several series of loaded vertical jumps provides information on the theoretical maximal force (F_0), theoretical maximal velocity (V_0), theoretical maximal power (P_{max}) and the imbalance between force and velocity (F-V_{IMB}). The purpose of this study is to observe the effects of 9 weeks of individualized F-V profile- based training during countermovement jumps (CMJ) in female ballet dancers. Methods: CMJ and mechanical outputs of forty-six dancers (Age=18.9±1.1years, body mass=54.8±6.1Kg, height=163.7±8.4cm) were estimated in a pre-post intervention. The control group (CG= 10 participants) continued with the standardized training regime (no resistance training), while the experimental group (EG= 36 subjects) performed 2 sessions over 9 weeks of a training plan based on their F-V profile. Results: The EG presented significant differences with large effect sizes in CMJ height (29.3±3.2cm vs 33.5±3.72cm), F_0 (24.1±2.2N/kg vs 29.9±2.8 N/kg) and V_0 (4±0.6m/s vs 3.2±0.5 m/s). Significant differences with a very large effect size were found in the F-V_{IMB} (43.8±15.3% vs 24.9±8.7%). Conclusion: A training program addressing F-V_{IMB} is an effective way to improve CMJ height in female ballet dancers.

Key Words: Dance, Performance, Force, Velocity, Jumping

Introduction

Dancers are considered as much athletes as artists, due to the excellent physical condition required by their demanding routines, and to the aesthetic component assigned to the choreography movements [1,2]. Ballet practitioners are required to achieve performance feats such as exciting and dramatic elevations (e.g., jumps) [3]. Dancers with a greater jump height are able to perform a wider range of skills during their flight time and implement more specific technical skills related to the aesthetic components of a dance choreography [4–6]. Therefore, sessions aimed at improving jump height are an important part of dance training. Moreover, it has been suggested that jump ability is one of the best predictors of dance performance [4,6–8].

However, it seems that dancers undertake very few supplementary training programs aimed at increasing strength, and consequently jump height [3,5,9,10], probably due to unconfirmed beliefs that resistance training will negatively impact aesthetic and artistic components of dance performance. Although previous studies suggest that a well-designed strength training program is beneficial in terms of increasing muscular strength without building excessive mass, and with no negative interference in the artistic and aesthetic requirements [3,11].

Investigations about fitness in dance, state that a fitter dancer is a better dancer, due to the observed association between specific physical fitness components such as muscular power and endurance, and qualitative aspects of dance performance [4,5,8,11]. Considering the amount of ballistic actions (i.e., jumps, accelerations and changes of direction) that dancers are required to perform [12,13], all the different elements of fitness must be included in their weekly training routine, including sessions focused on muscular strength and power output [4,5,8,11].

Over the last few years, new findings and field methods in ballistic actions have highlighted the importance of measuring the relationship between Force (F) and Velocity (V) mechanical capabilities during jumping performance, known as the Force-Velocity profile (F-V profile) [14–18]. Although the same power output (P_{max}) can be produced with different combinations of F and V ($P_{max} = F_0 \cdot V_0 / 4$) [19], the same value of P_{max} does not necessarily result in the same jump height [17]. However, there is an optimal F-V profile for each individual that maximizes jump performance for the same value of P_{max} [14,15,18,20,21]. Training plans that are specifically designed to improve P_{max}, without considering the detrimental increase of the actual imbalance between F and V (F-V$_{IMB}$), may result in a lack of change, or even a decrease in jumping performance [17]. The quantification of the actual and optimal F-V profile highlights the individual needs of each athlete, determining if the improvement of either force (Force deficit) or velocity (Velocity deficit) capabilities is required, to enhance jump performance while reducing the actual $F\text{-}V_{IMB}$ [15–17].

The actual and the optimal F-V profile can be computed during a series of loaded vertical jumps [20–24]. This field method provides the information related to theoretical maximal force (F_0), theoretical maximal velocity (V_0), slope of the F-V relationship ($F\text{-}V_{slope}$) and theoretical maximal power (P_{max}). The difference between actual and optimal F-V profiles for each individual represents the magnitude and the direction of the imbalance between force and velocity qualities ($F\text{-}V_{IMB}$), thus making the individual determination of force or velocity deficit possible [14,15,18,20,21].

While a number of studies have provided a reference about the F-V profile during jump performance in different sports, such as rugby league, sprinting and jumping, cycling, fencing, taekwondo, athletic sprinting or football [21,23,25–27], the number of studies that observe the effect of training programs aimed at reducing $F\text{-}V_{IMB}$, to reach optimal balance and enhance performance, are limited [17,18]. Previous studies with futsal, soccer and rugby players, analyzed the effectiveness of an optimized and individualized training program specifically designed to reduce $F\text{-}V_{IMB}$. The main findings concluded that training programs aimed at reducing the current $F\text{-}V_{IMB}$ are more effective to improve jumping performance than traditional resistance training that is common to all individuals, regardless of their actual and optimal F-V profiles [17]. Although different methods such as plyometric training or traditional weight training [5,6] have shown a positive effect on strength, power and jump height in dancers, investigations about the F-V profile appear to be sparse within this population.

Having taken into consideration the relevance of jump ability in dance performance, we have hypothesized that an individualized F-V profile-based training program may have potential benefits to improve jump height in ballet dancers. The purpose of this study is to observe the effects of 9 weeks of individualized training based on the F-V profile during the countermovement jump (CMJ) in female ballet dancers.

Methods.

Subjects

Forty-six professional female classic ballet dancers (Artist=20, First artist=17 and Soloist=9) with more than six years' experience (training volume of 9±2hours per week), participated in this study (Age=18.9±1.1years, body mass-BM=54.8±6.1Kg, height=163.7±8.4cm). All subjects were informed of the benefits and risks of the research through a structured consent form and PAR-Q. This study was approved by the Research Ethics Board of South Essex College in agreement with the Declaration of Helsinki.

Design

This experimental design, with a control and an experimental group, was designed to observe the effects of 9 weeks of individualized training, based on the reduction of the current F-V_{IMB} in the CMJ and the main variables of the F-V profile, on female ballet dancers in a pre- vs post-test comparison. The dependent variables of the study are defined as CMJ height, difference between the magnitude of the actual and optimal F-V profile for each individual (F-V_{IMB}), theoretical maximal force (F_0), theoretical maximal velocity (V_0), and theoretical maximal power (P_{max}) [16].

Methodology

All subjects were asked to meet in the morning to complete the anthropometric measurements. Body weight (kg) was measured using a Tanita SC-330, (Tanita Corp., Japan), and height (cm) was estimated with an aluminum stadiometer (Seca 713 model, Postfach, Germany). Measurements for lower-limb length (cm) were taken in two steps by an experienced researcher using a tape measure. First, with the participant lying down and ankle fully extended from iliac crest to toes; and second, in squatting position at 90° (knee flexion) from iliac crest to the ground. These measurements are required to obtain the distance covered by the center of mass during push-off (h_{PO}) [14,15,20].

Participants performed a standardized warm-up consisting of 10 minutes' jogging, dynamic stretching (plantar flexors, hip extensors, hamstrings, hip flexors, and quadriceps femoris), and preparatory countermovement jumps. There were two observers (one on either side of the subject) who provided verbal feedback about the starting height – set individually for each participant - in 90° (knee flexion) squat. The measurements required to determine the optimal F-V profile during jumping performance were the subject's body mass, jump height and h_{PO} [14,15,20]. To calculate the optimal F-V profile, each dancer performed 3 maximal vertical CMJs, with loads corresponding to 0%, 10%, 20%, 30%, 40%, 50% and 70% of their own body weight. The jumps were performed in a randomized order using an Olympic barbell, and with 2 minutes' recovery between jumps, and 4 minutes between loads to avoid fatigue effect [15,24]. The highest score of the 3 attempts for each load was selected for the F-V relationship analysis, and the 70% body weight load was included to determine that participants were able to jump about 10cm, as recommended in literature [16].

Values related to jump height and F-V profile were measured using a scientifically validated smartphone app (*My Jump 2*) on an iPhone device (iPhone 7; Apple, Cupertino, CA, USA), featuring a camera frame rate of 240fps [28]. This app showed good validity for the CMJ height in comparison to force platform ($r = 0.995$, $p < 0.001$). The app provides information regarding the magnitude and direction of the imbalance for each dancer (F-V_{IMB}), the theoretical maximal force (F_0), the theoretical maximal velocity (V_0), and the theoretical maximal power (P_{max}), according to Samozino's method [15,16,24].

After determining the F-V profile during jumping, groups were established according to the magnitude of the $F\text{-}V_{IMB}$: Well-Balanced<10%, Low Force-Velocity Deficit 10-40% and High Force-Velocity Deficit >40%, as suggested in a previous study [17,18]. A control group (CG) with 10 subjects (5 artists and 5 first artists) was randomly established; 5 subjects with low force deficit (LFD) and 5 subjects with high force deficit (HFD). An experimental group was also established with 2 subgroups based on the magnitude of the imbalance, resulting in an LFD subgroup with 16 subjects (9 artists, 4 first artists and 3 soloists) and an HFD subgroup with 20 subjects (6 artists, 8 first artists and 6 soloists). Both the CG and the EG continued with the standardized training regime (rehearsal, technique, Pilates, Gyrokinesis, Gyrotonic and cardiovascular training). While the CG did not follow any resistance training, a training intervention, adjusted to the $F\text{-}V_{IMB}$ of each subgroup, was designed for the EG. The strength training programs designed for the LFD subgroup mainly consisted of leg presses, deadlifts, squat jumps (SJ), Back-Squats, CMJs and single leg CMJs, while the HFD subgroup performed leg presses, SJs, single leg CMJs, Back-Squats, CMJs and single leg SJs. Details for the percentages of 1 repetition maximum (1RM) and body mass (BM), in addition to sets and repetitions corresponding to each exercise, are detailed in table 1 [17]. The experimental group performed 2 sessions per week (1 hour per session) for nine weeks, on Tuesdays and Fridays, with 3 minutes' recovery between trials, and 5 minutes between exercises. During the 3rd and 6th weeks of the intervention, CMJ height and F-V profile were retested (Sundays) to reallocate the dancers to the LFD or HFD groups according to the magnitude of their $F\text{-}V_{IMB}$ (See Table 2). A week after the nine weeks of intervention (Tuesday), jump height and F-V profile were measured for the pre-post comparison.

Statistical Analysis

All data are presented as means ± SD with IBM SPSS (IBM SPSS version 25.0; SPSS, Chicago, IL, USA) software. Normal distribution for the study variables was assessed with the Shapiro-Wilk Test. Inter- and intra-group comparisons for each variable were performed using a two-way (group x time) ANOVA with Bonferroni adjustment and level of significance set at $p \leq 0.05$. The reliability for the CMJ pre- and post-test were analyzed using an intraclass correlation coefficient-ICC (95% CI).

The magnitudes of change, within and between group comparisons, were calculated with the effect size (ES) of Coe [29]. The criterion for interpreting these magnitudes was <0.2 = trivial, 0.2 - 0.6 = small, 0.6 - 1.2 = moderate, 1.2 – 2 = large and >2.0 = very large [30].

Results

The baseline measures revealed that 46 out of 46 ballet dancers showed force deficit (44.1± 15%). Sixteen displayed LFD (10-40%), while twenty dancers presented HFD (>40%) [17,18]. Due to the reduction of the F-V_{IMB}, more dancers were reallocated to the LFD subgroup after having completed the re-tests at weeks 3 (CG=10 participants, LFD=22 participants and HFD=14 participants) and 6 (CG=10 participants, LFD=24 participants and HFD=12 participants). At the end of the intervention, no dancers showed HFD (CG=10 participants, LFD=36 participants). All the data (mean ± SD), regarding the tests performed throughout the 9 weeks of training, are presented in Table 2. The reliability analysis for the pre-CMJ height was (95% CI): 0.996 (0.987–0.999), and 0.995 (0.992–0.998) for the post-test.

The pre- and post-comparison in the control group (expressed as a grand mean) did not show significant differences for CMJ height (27.43±1.9cm), F-V_{IMB} (45.2±14.7%), F_0 (22.9±2.4N/kg) or V_0 (4.1±0.7m/s). Significant differences with trivial effect size were found for P_{max} (23.3±1.7W/kg vs 23.4±1.7W/kg; p-value=0.02; ES=0.05). After 9 weeks of intervention, the experimental group showed significant differences, with a large effect size in CMJ height (29.3±3.2cm vs 33.5±3.72cm; p-value=0.01; ES=1.21), F_0 (24.1±2.2N/kg vs 29.9±2.8 N/kg; p-value=0.01; ES=1.51), and V_0 (4±0.6m/s vs 3.2±0.5 m/s; p-value=0,01; ES=1.45), while significant differences with a very large effect size were found in F-V_{IMB} (43.8±15.3% vs 24.9±8.7%; p-value=0.01; ES=2.3), and no significant differences were found for P_{max} (23.8±3W/kg vs 23.8±3W/kg; p-value=0.93; ES=0). See Table 3.

The intergroup comparison showed no significant differences for the variables observed in the pre-test, although for the post-test, significant differences with large effect sizes were found in CMJ height (27.5±2cm vs 33.5±3.7cm; p-value=0.01; ES=1.7), F-V_{IMB} (45.3±14.7% vs 24.9±8.7%; p-value=0.01; ES=1.9), and V_0 (4.2±0.7m/s vs 3.2±0.5m/s; p-value=0.01; ES=1.8). Significant differences with a very large effect size were found in F_0 (23±2.4N/kg vs 29.9±2.8N/kg; p-value=0.01; ES=2.5). No significant differences were found for P_{max} (23.4±1.7W/kg vs 23.8±3W/kg; p-value=0.74; ES=0.1). See Table 4.

Discussion

The aim of this study was to observe the effect of an individualized F-V profile-based training program on jump performance with ballet dancers. Our results confirm the stated hypothesis that an individualized F-V profile-based training program may have potential benefits to improve jump height on ballet dancers. The main findings of this study confirm previous investigations by Jiménez-

Reyes et al, suggesting that training programs, based on the reduction of the current F-V imbalance, is an effective way of improving jump performance [17,18].

As observed in the results of this study, the baseline measurements obtained in the pre-test (46 out of 46 dancers showed F deficit) suggest that ballet dancers are velocity-oriented in terms of the F-V profile. This conclusion is in line with dance requirements of both training sessions and performance, such as a large number of repetitions for technical skills, vertical and horizontal jumps, changes of direction, and many stretch-shortening cycle actions with minimal foot support [12,13]. These results may be due to insufficient resistance training sessions, aimed at improving force capabilities and decreasing F-V_{IMB} [3,9]. Furthermore, the results of the CG (that was following its regular routine with no resistance training), after 9 weeks of training, reported no significant differences in CMJ, F-V_{IMB}, F_0 and V_0, although all of them increased slightly (See table 3).

The CG increasingly displayed significant differences with a trivial effect size in P_{max} (23.3±1.7W/kg vs 23.4±1.7W/kg; p-value=0.02; ES=0.05). The increase of P_{max} with hardly any change in CMJ height in the CG, may highlight that the improvement of P_{max}, while increasing F-V_{IMB}, could result in a lack of change, or even a decrease in jumping performance [17]. In relation to this, the P_{max} value obtained by the experimental group after the nine-week intervention is equal to the pre-test value, although the CMJ height was significantly higher with a larger effect size at post-intervention (29.3±3.2cm vs 33.5±3.72cm; p-value=0.01; ES=1.21), which provides an indication of the effectiveness of the proposed intervention in reducing F-V_{IMB} while increasing jump height [17]. This supports previous findings, suggesting that although there are different combinations of F_0 and V_0 ($P_{max} = F_0 \cdot V_0 / 4$) resulting in the same P_{max} [19], there is an optimal F-V profile to optimize ballistic actions [14,15,20].

During the nine-week intervention, changes in the CMJ height and in the F-V profile mechanical outputs can be observed (See table 2) in both experimental subgroups, LFD (9 artists, 4 first artists and 3 soloists), and HFD (6 artists, 8 first artists and 6 soloists). All participants in the experimental group (36 of 36) were sensitive to the proposed training programs. They increased force, decreased velocity capabilities and reduced the force deficit, while improving jump height. Our results may suggest that regardless of the company position [10], a training methodology based on F-V profiling is beneficial to improve jump height in ballet dancers, although studies with more participants from each company rank are required. After the pre-test, 10 and 16 subjects were allocated to the two experimental subgroups, LFD and HFD, respectively. At the end of the nine-week intervention, all the subjects in the HFD subgroup had reduced their imbalance to the threshold corresponding to LFD (F-V_{IMB}10-40%), and in the same way, subjects assigned to the LFD subgroup had decreased their deficit close to the limit of well-balanced (F-V_{IMB}<10%) [17,18].

The pre-test comparison within the CG and EG subgroups showed no significant differences for any of the variables observed in the study (See Table 4). However, the post-test presented a significant increase in CMJ height (27.5±2cm vs 33.5±3.7cm; p-value=0.01; ES=1.7), with a large effect size, and a significant decrease in F-V_{IMB} (45.3±14.7% vs 24.9±8.7%; p-value=0.01; ES=1.9) and V_0 (4.2±0.7m/s vs 3.2±0.5m/s; p-value=0.01; ES=1.8). Moreover, a significant increase was found in F_0 (23±2.4N/kg vs 29.9±2.8N/kg; p-value=0.01; ES=2.5) with a very large effect size. Our results are in line with previous studies on rugby, futsal and soccer players, suggesting that an optimized and individualized training program specifically addressing the F-V_{IMB} is more effective to improve jump performance than traditional resistance training [17,18].

The design of this study was based on a previous work by Jiménez-Reyes and colleagues [17]. Our study has fewer participants and all of them belong to the same discipline (46 ballet dancers vs 84 soccer and rugby players). The inclusion of athletes from different sports may be a reason for the wider range of F-V_{IMB} that was reported by Jimenez-Reyes, who included athletes sub-grouped according to either F and V deficit, as well as subjects with a well-balanced profile (something really uncommon), while the totality of our dancers showed F deficit. The intervention lasted for nine weeks in both studies, and the design of the training sessions for our study was based on the same program proposed by Jimenez-Reyes and colleagues to reduce F-V_{IMB}.

Studies using plyometric and traditional weight training have reported positive effects on exercises for dancers to jump, without emphasis on any artistic skill, and once they have increased their flight time (elevated themselves higher), they could implement specific technical skills for their dance performance [5,6]. Considering the high amount of ballistic actions that are part of ballet performance (vertical jumps, horizontal jumps, changes of direction, etc.) [12,13], this methodology may provide practitioners with a more effective way of enhancing these abilities.

This study has limitations that must be mentioned for a greater understanding of the obtained results and to avoid misconceptions. It is important to notice that although the reduction of the F deficit over 9 weeks' training has been significant in the experimental group, our study has only observed the effect of resistance training designed to improve F capabilities, due to the absence of dancers with V deficit. In addition, a longer intervention would be required for the dancers to achieve their optimal balance, to design optimized training that would maintain the optimal F-V profile, and in the meanwhile to observe the CMJ performance [18]. The analysis of male dancers could also provide different results in terms of the magnitude and direction of $F\text{-}V_{IMB}$, due to the different choreographic demands and training programs [10]. Furthermore, the changes in CMJ height and the F-V profile variables are not based on ballet-specific jumps (i.e.; “Sauté in first position”, “Entrechats quatres”, “tours en l’air”, etc.). Therefore, future studies could assess if the results of the current study could actually transfer to the execution of ballet-specific actions.

Practical applications

To our knowledge, this is the first study to observe the effect of an individualized F-V profile-based training program during jumping in dancers. Our study provides more evidence about the effectiveness of this methodology and supports the use of $F\text{-}V_{IMB}$ as a useful variable for prescribing optimal resistance training to improve jumping performance. As observed in the results of this study, the assessment of the $F\text{-}V_{IMB}$ for each individual as a training variable provides the opportunity to design a more optimal training plan adjusted to the individual needs of each subject [16–18]. The methodology used in this study may be useful for coaches and dance teachers who wish to individualize the prescription of their strength training sessions.

Conclusion

A training plan addressing $F\text{-}V_{IMB}$ is an effective way of improving countermovement jump performance in female ballet dancers, regardless of their rank position. This study suggests the individualization of training programs aimed at reducing $F\text{-}V_{IMB}$ as a useful variable to improve jumping ability.

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REFERENCES

1. Gamboa JM, Roberts LA, Maring J, Fergus A. Injury Patterns in Elite Preprofessional Ballet Dancers and the Utility of Screening Programs to Identify Risk Characteristics. *J Orthop Sport Phys Ther*. 2008. doi:10.2519/jospt.2008.2390

2. Allen N, Nevill A, Brooks J, Koutedakis Y, Wyon M. Ballet Injuries: Injury Incidence and Severity Over 1 Year. *J Orthop Sport Phys Ther*. 2012. doi:10.2519/jospt.2012.3893
3. Koutedakis Y, Stavropoulos-Kalinoglou A, Metsios G. The Significance of Muscular Strength in Dance. *J Danc Med Sci*. 2005;9(1):29-34.
4. Angioi M, Metsios GS, Twitchett E, Koutedakis Y, Wyon M. Association between selected physical fitness parameters and esthetic competence in contemporary dancers. *J Dance Med Sci*. 2009;13(4):115-123.
5. Brown AC, Wells TJ, Schade ML, Smith DL, Fehling PC. Effects of Plyometric Training Versus Traditional Weight Training on Strength, Power, and Aesthetic Jumping Ability in Female Collegiate Dancers. *J Danc Med Sci*. 2007.
6. Hewett TE, Stroupe AL, Nance TA, Noyes FR. Plyometric training in female athletes: Decreased impact forces and increased hamstring torques. *Am J Sports Med*. 1996. doi:10.1177/036354659602400611
7. Koutedakis Y, Jamurtas A. The dancer as a performing athlete: Physiological considerations. *Sport Med*. 2004. doi:10.2165/00007256-200434100-00003
8. Rafferty S. Considerations for integrating fitness into dance training. *J Dance Med Sci*. 2010;14(2):45-49.
9. Wyon MA, Deighan MA, Nevill AM, et al. The cardiorespiratory, anthropometric, and performance characteristics of an international/national touring ballet company. *J Strength Cond Res*. 2007. doi:10.1519/R-19405.1
10. Wyon MMA, Allen N, Angioi MM, Nevill A, Twitchett E. Anthropometric Factors Affecting Vertical Jump Height in Ballet Dancers. *J Danc Med Sci*. 2006;10(3-4):106-110.
11. Koutedakis Y. Fitness for Dance. *J Danc Med Sci*. 2005;9(1):5-6. http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=17480896&site=ehost-live.
12. Dowse RA, McGuigan MR, Harrison C. Effects of a Resistance Training Intervention on Strength, Power, and Performance in Adolescent Dancers. *J Strength Cond Res*. 2017. doi:10.1519/JSC.0000000000002288
13. Jeffries AC, Wallace LW, Coutts AJ. Quantifying Training Loads in Contemporary Dance. *Int J Sports Physiol Perform*. 2016:21. doi:10.1123/ijspp.2015-0012
14. Samozino P, Rejc E, Di Prampero PE, Belli A, Morin JB. Optimal force-velocity profile in ballistic movements-Altius: Citius or Fortius? *Med Sci Sports Exerc*. 2012;44(2):313-322. doi:10.1249/MSS.0b013e31822d757a
15. Samozino P, Edouard P, Sangnier S, Brughelli M, Gimenez P, Morin JB. Force-velocity profile: Imbalance determination and effect on lower limb ballistic performance. *Int J Sports*

Med. 2014;35(6):505-510. doi:10.1055/s-0033-1354382
16. Morin JB, Samozino P. Interpreting power-force-velocity profiles for individualized and specific training. *Int J Sports Physiol Perform*. 2016;11(2):267-272. doi:10.1123/ijspp.2015-0638
17. Jiménez-Reyes P, Samozino P, Brughelli M, Morin JB. Effectiveness of an individualized training based on force-velocity profiling during jumping. *Front Physiol*. 2017;7(JAN). doi:10.3389/fphys.2016.00677
18. Jiménez-Reyes P, Samozino P, Morin J-B. Optimized training for jumping performance using the force-velocity imbalance: Individual adaptation kinetics. Boullosa D, ed. *PLoS One*. 2019;14(5):e0216681. doi:10.1371/journal.pone.0216681
19. Jaric S. Force-velocity Relationship of Muscles Performing Multi-joint Maximum Performance Tasks. *Int J Sports Med*. 2015. doi:10.1055/s-0035-1547283
20. Samozino P, Morin JB, Hintzy F, Belli A. A simple method for measuring force, velocity and power output during squat jump. *J Biomech*. 2008;41(14):2940-2945. doi:10.1016/j.jbiomech.2008.07.028
21. Jiménez-Reyes P, Samozino P, Cuadrado-Peñafiel V, Conceição F, González-Badillo JJ, Morin JB. Effect of countermovement on power–force–velocity profile. *Eur J Appl Physiol*. 2014;114(11):2281-2288. doi:10.1007/s00421-014-2947-1
22. Giroux C, Rabita G, Chollet D, Guilhem G. What is the best method for assessing lower limb force-velocity relationship? *Int J Sports Med*. 2014;36(2). doi:10.1055/s-0034-1385886
23. Giroux C, Rabita G, Chollet D, Guilhem G. Optimal balance between force and velocity differs among world-class athletes. *J Appl Biomech*. 2016;32(1):59-68. doi:10.1123/jab.2015-0070
24. Jiménez-Reyes P, Samozino P, Pareja-Blanco F, et al. Validity of a simple method for measuring force-velocity-power profile in countermovement jump. *Int J Sports Physiol Perform*. 2017;12(1):36-43. doi:10.1123/IJSPP.2015-0484
25. Marcote-Pequeño R, García-Ramos A, Cuadrado-Peñafiel V, González-Hernández JM, Gómez MÁ, Jiménez-Reyes P. Association Between the Force-Velocity Profile and Performance Variables Obtained in Jumping and Sprinting in Elite Female Soccer Players. *Int J Sports Physiol Perform*. July 2018:1-21. doi:10.1123/ijspp.2018-0233
26. Hervéou T, Rahmani A, Chorin F, Frère J, Ripamonti M, Durand S. Force-velocity muscular profiles and jumping performances of soccer goalkeeper. *Science and Sports*. 2018.
27. de Lacey J, Brughelli M, McGuigan MR, Hansen K, Samozino P, Morin J-B. The Effects of Tapering on Power-Force-Velocity Profiling and Jump Performance in Professional Rugby League Players. *J Strength Cond Res*. 2014. doi:10.1519/JSC.0000000000000572

28. Balsalobre-Fernández C, Glaister M, Lockey RA. The validity and reliability of an iPhone app for measuring vertical jump performance. *J Sports Sci*. 2015;33(15):1574-1579. doi:10.1080/02640414.2014.996184

29. Coe R. It's the effect size, stupid - What effect size is and why it is important. *Annu Conf Briditsh Educ Res Assoc*. 2002.

30. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41(1):3-12. doi:10.1249/MSS.0b013e31818cb278